ATTACHMENT C – GROUNDWATER MONITORING AND LIMITATIONS **Permit Number: WQ0034380** **Version: 1.0**

Monitoring wells: MW-1, MW-2, MW-3, MW-4, MW-5, MW-6 and MW-7

GROUNDWATER CHARACTERISTICS	GROUNDWATER STANDARDS		MONITORING REQUIREMENTS		
Parameter Description - Parameter Code	**Daily Maximum**		**Frequency Measurement**	**Sample Type**	**Footnotes**
Carbon, Tot Organic (TOC) – 00680		mg/l	3 x Year	Grab	1, 4
Chloride (as Cl) – 00940	250	mg/l	3 x Year	Grab	1
Coliform, Fecal MF – 31616		#/100ml	3 x Year	Grab	1
Nitrogen, Ammonia Total (as N) – 00610		mg/l	3 x Year	Grab	1
Nitrogen, Nitrate Total (as N) – 00620	10	mg/l	3 x Year	Grab	1
pH – 00400	6.5-8.5	s.u.	3 x Year	Grab	1, 2
Phosphorus, Total (as P) – 00665		mg/l	3 x Year	Grab	1
Solids, Total Dissolved- 180 Deg C – 70300	500	mg/l	3 x Year	Grab	1
Water level, distance from measuring point – 82546		ft	3 x Year	Calculated	1, 2, 3

1. 3 x Year monitoring shall be conducted in March, July & November; Annual monitoring shall be conducted every November.
2. The measurement of water levels shall be made prior to purging the wells. The depth to water in each well shall be measured from the surveyed point on the top of the casing. The measurement of pH shall be made after purging and prior to sampling for the remaining parameters.
3. The measuring points (top of well casing) of all monitoring wells shall be surveyed to provide the relative elevation of the measuring point for each monitoring well. The measuring points (top of casing) of all monitoring wells shall be surveyed relative to a common datum.
4. If TOC concentrations greater than 10 mg/l are detected in any downgradient monitoring well, additional sampling and analysis must be conducted to identify the individual constituents comprising this TOC concentration. If the TOC concentration as measured in the background monitor well exceeds 10 mg/l, this concentration will be taken to represent the naturally occurring TOC concentration. Any exceedances of this naturally occurring TOC concentration in the downgradient wells shall be subject to the additional sampling and analysis as described above.
5. Monitoring wells shall be reported consistent with the nomenclature and location information provided in Figure 1 and this attachment.

Figure 2 – Aerial Map	
WQ0034380	Pruitt Road, Kinston, NC 28501
Sanderson Farms, Inc. (Processing Division)	Latitude: 35° 15′ 03″
Sanderson Farms WWTF	Longitude: -77° 40′ 35″

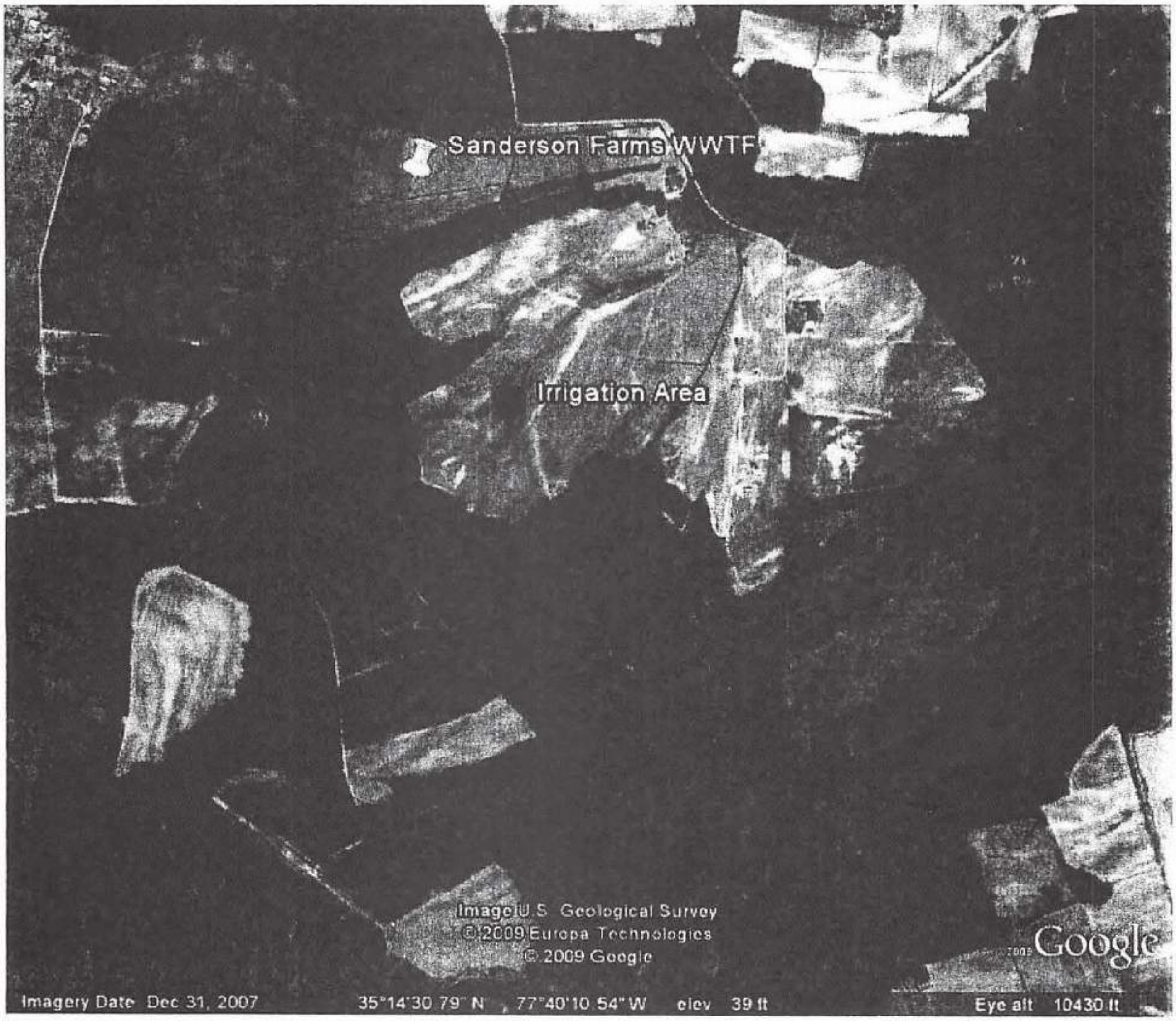


Figure 3 – Directional Map	
WQ0034380	Pruitt Road, Kinston, NC 28501
Sanderson Farms, Inc. (Processing Division)	Latitude: 35° 15′ 03″
Sanderson Farms WWTF	Longitude: -77° 40′ 35″

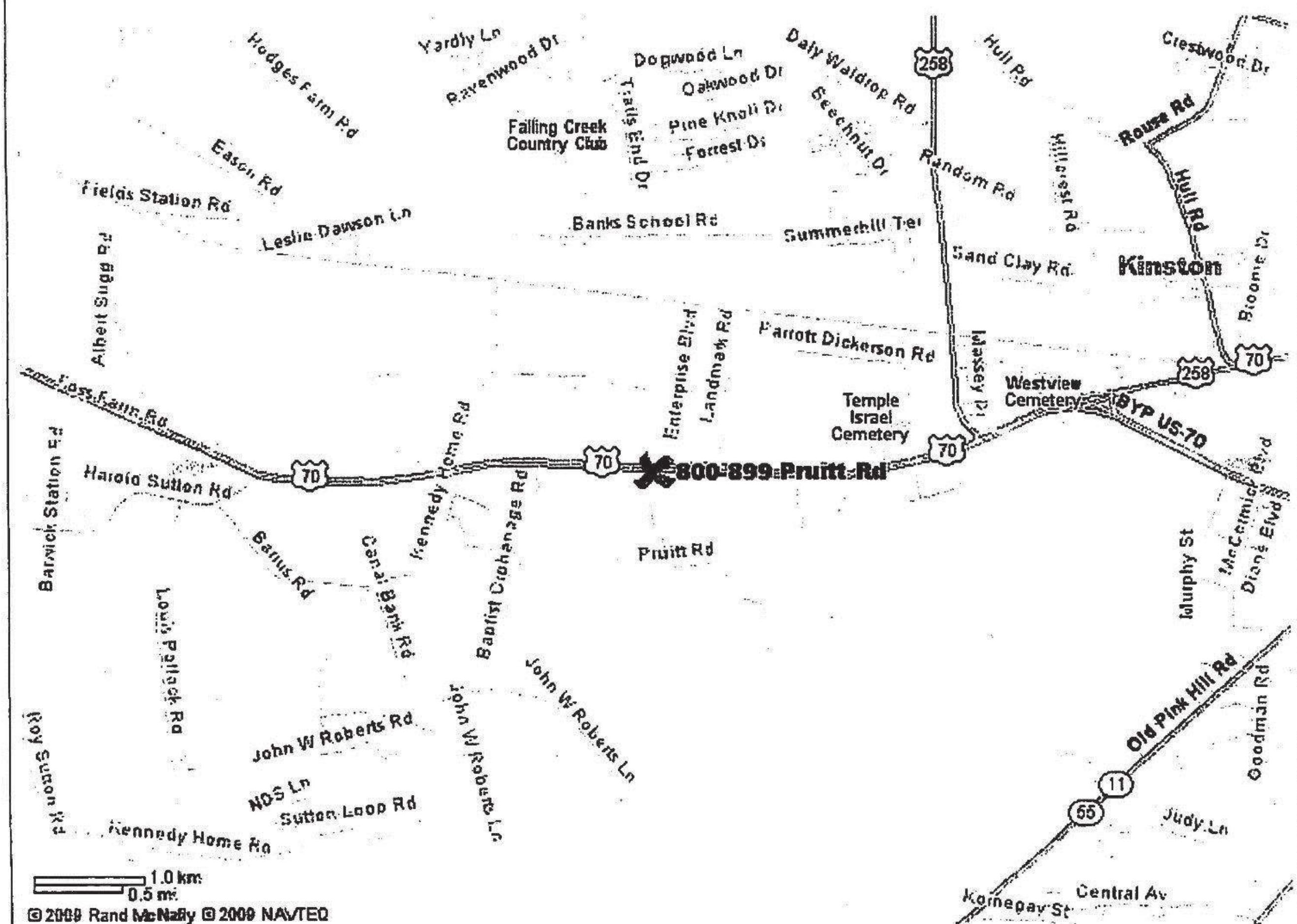


Figure 4 – Topographic Map	
WQ0034380	Pruitt Road, Kinston, NC 28501
Sanderson Farms, Inc. (Processing Division)	Latitude: 35° 15′ 03″
Sanderson Farms WWTF	Longitude: -77° 40′ 35″

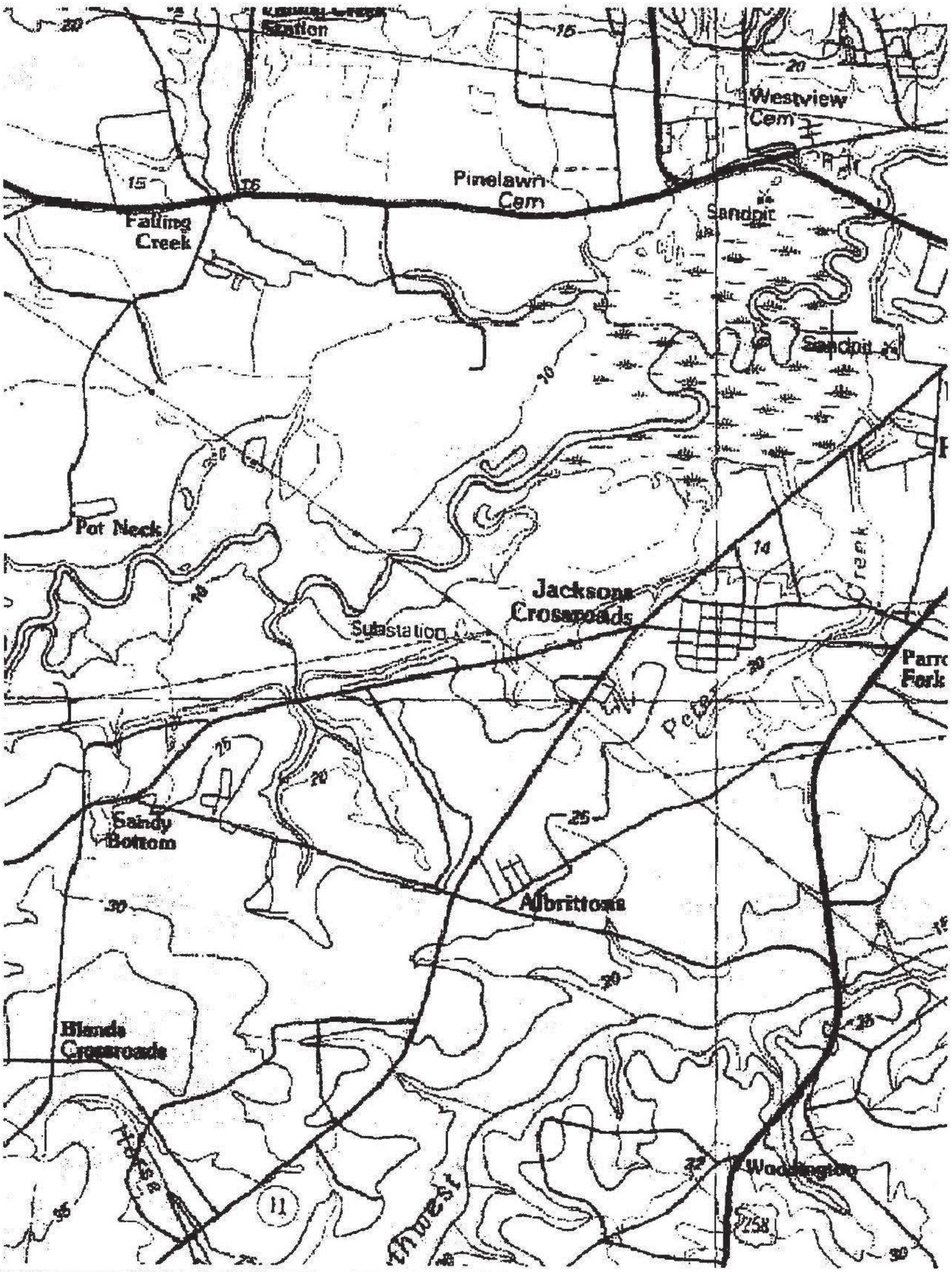


EXHIBIT K

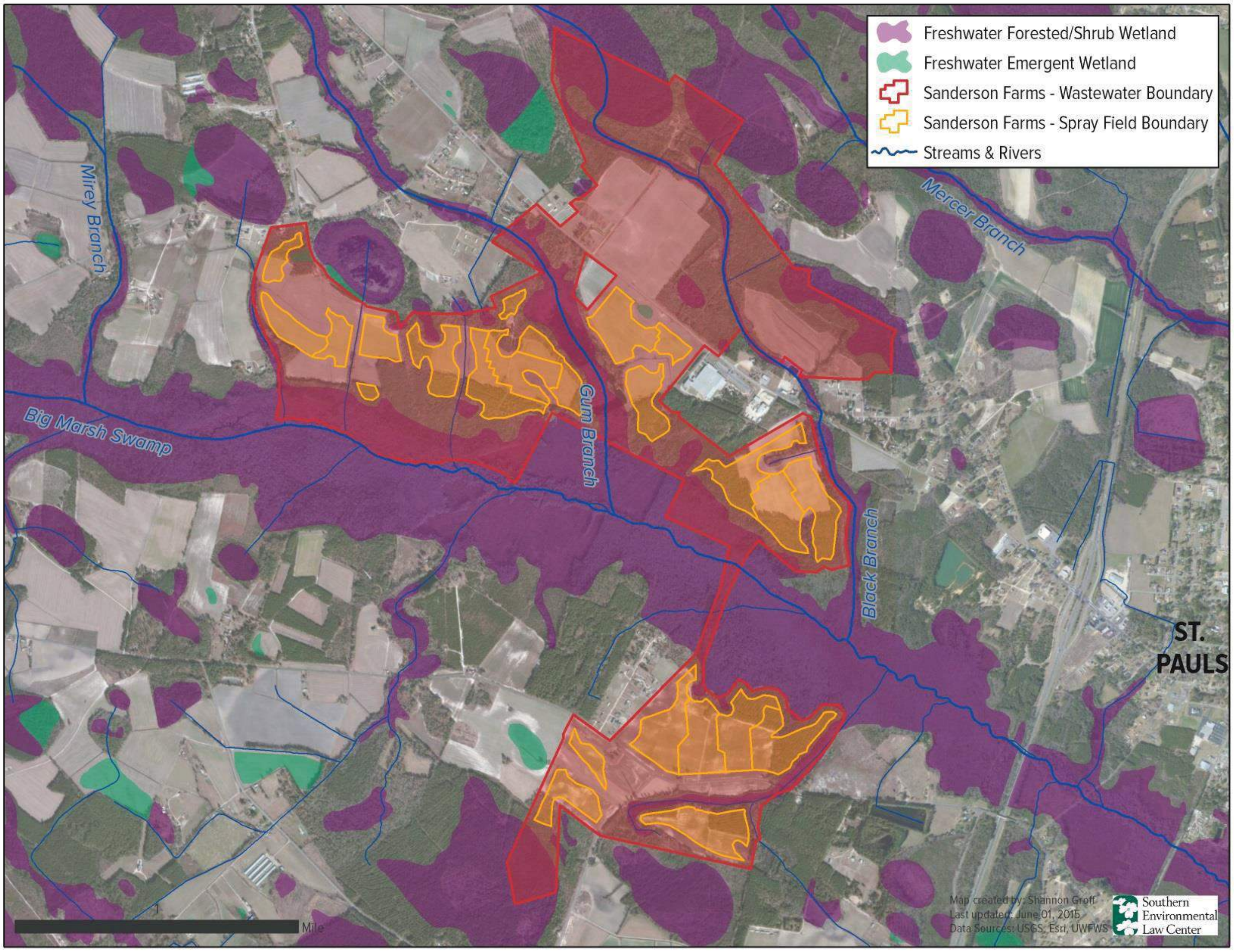

Freshwater Forested/Shrub Wetland
Freshwater Emergent Wetland
Sanderson Farms - Wastewater Boundary
Sanderson Farms - Spray Field Boundary
Streams & Rivers
Mirey Branch
Mercer Branch
Big Marsh Swamp
Gum Branch
Black Branch
ST. PAULS
Mile
Map created by: Shannon Groff
Last updated: June 01, 2015
Data Sources: USGS, Esri, UWFWS
Southern Environmental Law Center

EXHIBIT L

AMERICAN
Scientist

FEATURE ARTICLE

Impacts of Industrial Animal Production on Rivers and Estuaries

Animal-waste lagoons and sprayfields near aquatic environments may significantly degrade water quality and endanger health

Michael Mallin

On June 22, 1995, the citizens of Onslow County in North Carolina's Coastal Plain awoke to a remarkably unpleasant sight. During the previous evening a swine waste-holding lagoon had ruptured, sending approximately 25 million gallons (95 million liters) of concentrated feces and urine across a road and fields and into the New River, a coastal namesake of the far longer and older Appalachian river. During the following day the putrefying mass traveled approximately 22 miles down the river, where it slowed just upstream of the city of Jacksonville. Over the next few days, some of this waste load would work its way down into the New River Estuary. There its effects on marine life would linger for three months.

+ enlarge image

For the previous year, my laboratory at the University of North Carolina at Wilmington had been studying the water quality of the New River Estuary in collaboration with JoAnn Burkholder's laboratory at North Carolina State University. After a hasty exchange of phone calls early on the 23rd, each lab sent a team to help investigate the effects of the enormous spill. My research assistant, Matt McIver, and I drove from Wilmington north to the town of Richlands, which has the sign "Welcome to Richlands-Town of Perfect Water" at the city limits. Finding a bridge under which the New River passed, we scrambled down the slope to find carcasses of fish representing numerous local species scattered along the bank and hanging in streamside bushes, the water turned murky brown with turbidity and a nauseating stench in the air. During the rest of the afternoon we checked various other accessible locations along the river, collecting water samples while state fish and wildlife workers picked up dead fish by the bucketload.

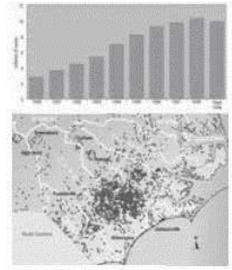
The seeming uniqueness of the event, combined with our available background data, made for an excellent opportunity to study the effects of a major waste-load spill on a river and its estuary. For the rest of the summer and early fall my laboratory conducted intensive physical, chemical and biological analyses of the estuary as Burkholder's NCSU lab contributed similar information for the river.

The event turned out not to be so unique after all. On July 3, 9 million gallons (34 million liters) of poultry waste poured from a breach in a lagoon in nearby Duplin County after heavy rains, polluting Limestone Creek and the Northeast Cape Fear River. On August 8, during dry weather, one million gallons (3.8 million liters) of swine waste leaked from a lagoon into Harris Creek in Brunswick County, and from there spread into a series of freshwater tidal creeks draining into the Cape Fear Estuary.

Several other well-publicized swine waste-lagoon spills also took place that summer in the Cape Fear and Neuse river basins. The following year Hurricane Fran swept through eastern North Carolina, followed by Hurricane Bonnie in 1998 and, as this article was in preparation, the most devastating flooding the region has seen, the triple punch from Hurricanes Dennis, Floyd and Irene in September and October 1999. Each hurricane season dumped large quantities of rain in floodplains dominated by industrial poultry and livestock operations, causing waste-holding lagoons to rupture or overflow and washing waste from sprayfields into rivers and estuaries simultaneously contaminated with overflows of domestic and industrial sewage. The resilience of a large and productive river and estuarine system has been sorely tested.

A Changing Rural Landscape

Many Americans have grown up on storybook images of the family farm, complete with chicken coop and pigs wallowing outdoors in a pen. Traditional mixed farming still predominates in developing countries; however, in the U.S. and elsewhere in the developed world, a typical poultry or swine operation bears scant resemblance to Old MacDonald's farm. In recent years the number of individual swine farmers has dropped dramatically, while the numbers of swine owned by a few producers has greatly increased. This trend appears to have been responsible for reducing production costs and raising productivity in the industry. In the current model hog-production operation, hundreds to thousands of animals are fed and raised wholly indoors in large, rectangular hog houses. The feces and urine generated by the animals are washed through slats in the building floor into a series of trenches and pipes beneath the structure that carry the waste outdoors into a large holding pit known as a waste lagoon. When the waste in the lagoon reaches a certain height, some of it is pumped out and sprayed onto surrounding fields that are often planted with a cover crop such as bermudagrass.



+ enlarge image

These factory-style concentrated animal operations, or CAOs, are based on models used extensively for poultry in Arkansas and eastern states such as Maryland, Delaware and Virginia, particularly in the region known as the Delmarva Peninsula. The industrialization of the poultry industry began in the 1950s; industrial hog farming is a somewhat newer development. Concentrated operations began replacing family-style hog farms in the Midwest during the 1970s and early 1980s and achieved popularity among pork producers in North Carolina in the late 1980s. Sympathetic legislators ushered bills through the N.C. General Assembly that largely exempted such operations from local zoning ordinances, mandatory inspections and nuisance lawsuits and gave the industry a series of tax breaks as well. (This story is told by former Senator Robert Morgan in the 1998 book *Pigs, Profits, and Rural Communities*.)

+ enlarge image

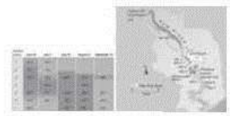
The favorable regulatory climate and availability of an inexpensive waste-disposal system led to a phenomenal rise in the North Carolina swine population, from 2.7 million head in 1990 to more than 10 million head in 1998. (According to the N.C. Department of Agriculture, the number stood at 9.9 million when Hurricane Floyd struck.) North Carolina is now, behind Iowa, the second largest state in hog production. Most of the North Carolina CAOs are located in the lower Cape Fear and Neuse river watersheds. From the scientific standpoint this proliferation of concentrated operations has transformed the state's coastal plain into a laboratory for examining the impact of industrial-scale animal production, and its waste outputs, on river and estuarine systems. In this article I present the results of our waste-spill investigations and discuss the vulnerability of the waste-disposal systems now associated with hog production to both normal rainfall and major weather events. Our research has sought to explore the pathways by which nutrient-enriched wastes reach water bodies and to determine how these nutrient loads affect the water quality of coastal streams.

Tracking the Impacts of Spills

When there is insufficient dissolved oxygen in a stream, fish and other aquatic organisms can die. A healthy stream, according to North Carolina water-quality standards, has a dissolved-oxygen level of 5.0 mg/L (milligrams per liter, equivalent to parts per million). The 1995 waste-lagoon spill in the New River caused river dissolved oxygen to drop to levels less than 1.0 mg/L. The fish kill extended along more than 20 miles of river (Burkholder *et al.* 1997). The spill also caused high levels of turbidity, or particulate matter in the water. Excess particulates swirling in a river can block sunlight needed for aquatic plant photosynthesis and interfere with the feeding of fish and shellfish. The North Carolina turbidity standard for water quality is 50 units for freshwater and 25 units for estuarine water. After the spill, turbidity in the New reached 92.8 units.

In addition, high concentrations of nitrogen and phosphorus contaminated the length of the river. What do nutrient levels of this magnitude mean to an aquatic ecosystem? Data that we have accumulated from our research in the Cape Fear watershed indicate that typical river ammonium levels range from 0.01 to 0.30 mg/L, nitrate ranges from 0.05 to 1.00 mg/L and phosphate from 0.005 to 0.150 mg/L. Ammonium levels of 40 mg/L are considered capable of causing death or injury to fish and other aquatic life through direct toxicity. Ammonium in the New River jumped to 46.21 mg/L after the spill.

+ enlarge image

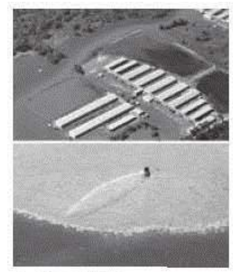


+ enlarge image

However, the most common response to nutrient loading is the formation of blooms of phytoplankton (single-celled algae), some of which can be noxious or toxic to fish and invertebrates. When the hog-waste plume reached the upper New River Estuary in Jacksonville Harbor, the nutrient load caused phytoplankton blooms exceeding 300 µg/L (micrograms per liter, or parts per billion) of chlorophyll *a* (a measure of algal biomass). As a reference, the N.C. Division of Water Quality considers chlorophyll *a* concentrations exceeding 40 µg/L to indicate a nuisance algal bloom.

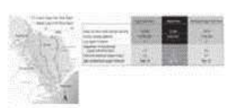
Several miles downstream from Jacksonville in the New River Estuary there was an algal bloom reaching 110 µg/L of chlorophyll a that was of special interest. This bloom contained high concentrations of the harmful algal species *Phaeocystis globosa*, which had not previously been seen in the New River Estuary. Also coinciding with this event was a bloom of the toxic dinoflagellate *Pfiesteria piscicida* of 1,200 cells/mL. Exhaustive field and laboratory research by JoAnn Burkholder and Howard Glasgow (1997) has established that *Pfiesteria* cell counts of 300/mL or greater are sufficient to kill numerous species of fish. Some 10,000 Atlantic menhaden were found dead in the estuary at the location of the *Pfiesteria* bloom, with many of the fish exhibiting cloacal lesions. Burkholder and her colleagues also found that the *Pfiesteria* populations present tested as toxic in follow-up laboratory bioassays.

The nutrients from the waste load affected the estuary for an extended period. A massive algal bloom occurred early on in the lower river and then spread downstream into the estuary. Freshwater input to the estuary is low compared with other area estuaries; thus the tides and the poorly flushed hydrology of the estuary caused the bloom to be retained until late August. Along with the blooms, dissolved-oxygen levels in the bottom waters of the lower river and upper estuary dropped below 1.0 mg/L, creating an unhealthy habitat for bottom-dwelling fish and invertebrates.



+ enlarge image

With colleagues from my own institution and NCSU, I conducted a detailed assessment of the effects of poultry-waste lagoon accident a few weeks later (Mallin *et al.* 1997). This spill caused very low dissolved-oxygen levels (0.3 mg/L) and a fish kill in Limestone Creek before its plume entered the Northeast Cape Fear River. State water-quality biologists had previously rated the condition of the Limestone Creek streambed invertebrate community as "excellent." A reassessment after the spill led them to reclassify the community as "poor." A key indicator of water quality is biochemical oxygen demand, or the oxygen consumed by microorganisms decaying organic material in water. The oxygen demand from the waste load that entered the river caused a sag in the dissolved-oxygen level, which reached a minimum 10 days later 90 kilometers downstream near the town of Castle Hayne. This minimum represented the lowest dissolved-oxygen levels in 23 years of records at the Castle Hayne sampling site. Again the effects of the spill proved persistent. Unusually high levels of nutrients were found at this distant downstream site during the month following the spill.



+ enlarge image

As with the other recorded spills, the Brunswick County swine-lagoon accident introduced high turbidity and led to low dissolved-oxygen levels (0.1 mg/L) in Harris Creek. This incident also caused algal blooms, with chlorophyll *a* exceeding 100 µg/L in Harris Creek, which then spread throughout the associated tidal-creek network. The low dissolved oxygen and surface algal blooms in the creek system remained for about three weeks, until a substantial rainfall led to improved water quality.

Another important component of swine and poultry waste is the concentrated microbial mass excreted by the animals. Although much of this microbial flora is benign, some of the microbes are disease-causing.Vincent R. Hill and Mark D. Sobsey of the University of North Carolina at Chapel Hill (1998) have noted that many of the pathogenic microbes (bacteria, protozoa and viruses) in swine and poultry waste are able to infect people. Therefore, animal-waste spills present a direct health threat to humans contacting affected waters.

Fecal coliform bacteria are commonly used as indicators of the presence of pathogens in waters affected by polluted inputs. The N.C. Division of Water Quality uses 200 colony-forming units per 100 milliliters (200 CFU/100mL) as the state standard for safe human contact with water bodies. The spill incidents caused very high fecal coliform counts in the receiving streams-including a remarkable 3.4-million-units measurement in the New following the June swine-waste spill.

Fecal coliform counts in the stream water decreased considerably after a few days in each case. However, much of the bacterial load in the New River spill settled to the sediments, where Burkholder and her colleagues (1997) recorded fecal coliform counts exceeding 5,000 CFU/100 mL of sediment slurry for up to 61 days after the spill. The high sediment counts mean that natural or human disturbance of these contaminated sediments could resuspend potentially dangerous amounts of bacteria and other microbes back into the water column for weeks after a spill event. Thus, water that appears to be safe based on water-column fecal-coliform counts may still represent a human health danger.

Hurricanes: Not Just "Mother Nature"

Under dry to average conditions, animal waste from livestock and poultry operations enters rivers through accidental waste spills and runoff from sprayfields. In the Southeast, frequented by hurricanes, the vulnerability of these waste-handling systems to severe storms is a special concern.

State records show that in 1996, the extreme rainfall associated with the September passage of Hurricane Fran led to ruptures, excessive overflows and floodplain inundations at some 22 animal-waste lagoons in North Carolina. At least four swine-waste lagoons ruptured or were inundated along the Northeast Cape Fear River, contributing to extended near-anoxic periods and fish and invertebrate kills. Meanwhile power failures led to the rerouting of untreated human sewage into the three main branches of the Cape Fear River. But the impact of the swine-waste lagoon overflows appears to have been much more potent and long-lasting.

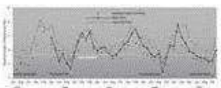
My laboratory collaborated with Martin Posey's Benthic Ecology Laboratory at UNC-Wilmington to assess the effects of Hurricane Fran on water quality and benthic organisms in the Cape Fear system (1999). We found that all of the main tributaries were affected by Fran, but the most severe and persistent water-quality effects occurred in the Northeast Cape Fear River, where the amount of human sewage spilled was smaller but where impacts from swine lagoons were coincidentally the greatest.

	Colly Creek	Great Coharrie Creek
[illegible]	6	35
[illegible]	5.3	9.7
[illegible]	[illegible]	0.570
[illegible]	8	2100

+ enlarge image

In August 1998 Hurricane Bonnie struck the Cape Fear region. Extensive rains were also associated with this event. There was only one major swine-lagoon incident reported, possibly a result of improvements in operations in response to increased lagoon inspections by state regulators during the previous two years. However, the siting of waste lagoons on river floodplains remained a major environmental problem in the region. Several days after Bonnie's passage our field biologists observed CAO operators spraying large quantities of waste onto sprayfields already saturated by rain from the hurricane and subsequent rainfall. This may have been done to prevent the waste lagoons in that area from overtopping in response to the high rainfall. Such spraying, also observed after Hurricane Floyd, is a legal practice but environmentally unsound, since saturated sprayfields cannot absorb the waste.

We collected water samples for five-day measurements of biochemical oxygen demand in the river just downstream of the spray activity. The normal five-day total oxygen demand in this river is 1.0 mg/L. The samples downstream from the spraying yielded five-day oxygen-consumption totals of 9.0 mg/L, compared with 4.0 mg/L downstream from municipal sewage bypasses. Dissolved oxygen in the lower Northeast Cape Fear River stayed at near anoxic levels for almost two weeks. The fish kill associated with these conditions was massive (more than 10,000 fish); affected were numerous fish species including largemouth bass, catfish, chain pickerel, hogchokers and various sunfish, as well as invertebrates including blue crabs, shrimp and crayfish. Dissolved oxygen in that area of the river did not recover to a "healthy" level of 5.0 mg/L for two months. Spraying large amounts of waste onto saturated fields thus appears to pollute downstream waters in ways similar to lagoon spills or overtoppings.



+ enlarge image

In the language of water quality, discharges from sewage-treatment plants or animal-waste lagoons are measurable "point sources" of pollution. Runoff of agricultural chemicals and nutrients from the land, by contrast, is difficult to measure. To investigate the effect in a storm of runoff from animal-waste sprayfields, we compared drainage from a relatively pristine stream basin (Colly Creek) with that of a basin rich in concentrated animal operations (Great Coharrie Creek) five days after Hurricane Bonnie. Drainage water in Great Coharrie Creek had twice the biochemical oxygen demand, 10 times the total phosphorus and fecal coliform bacterial counts 250 times higher than that of Colly Creek, a situation caused by runoff initiated by the heavy rainfall. Thus, even in the absence of major lagoon accidents, the siting of swine facilities and sprayfields on river floodplains can be environmentally hazardous.

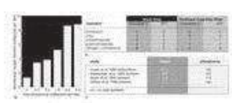
An examination of monthly dissolved-oxygen levels in the three main branches of the Cape Fear system shows how waste from concentrated animal operations influences river water quality under these conditions. Dramatic drops in dissolved oxygen in the Cape Fear system can be clearly associated with the events I have described: the poultry-waste lagoon rupture (July 1995), hurricanes in 1996, 1998 and 1999, with the associated swine-lagoon accidents, waste spraying onto rain-saturated floodplain fields and municipal waste overflows, and discharging of swamp water into rivers.

Chronic Water-Quality Problems

The spectacular consequences of flooding in areas dominated by concentrated animal operations are one thing; the effect of chronic pollutant loading is another. The quantities of waste generated by these operations are enormous, and disposal is a continuing challenge.

Liquid waste or poultry litter is continually deposited on fields adjoining these operations after storage in the lagoon. Like all manures, these are highly concentrated sources of nutrients such as phosphorus and nitrogen. Normal rainfall events carry a portion of this nutrient load either overland across the field or through the shallow groundwater into nearby receiving streams. Typically, when nutrient concentrations are measured in runoff and streams around these operations, the readings are high enough to cause damage to aquatic ecosystems. Sewage-treatment plants and row-crop agriculture can be other significant sources of stream nutrients.

The effects of nutrient loading are sometimes manifested as algal blooms in receiving waters. During summer low-flow periods, our routine monitoring of streams in the Cape Fear River basin occasionally detects algal blooms in streams draining areas rich in animal operations and in streams downstream of point-source discharges. However, in coastal-plain streams the effect of nutrient loading on ambient dissolved oxygen may be an even more crucial problem.



+ enlarge image

The surface-water systems in the major swine-production areas in coastal North Carolina are composed primarily of blackwater streams. These waters are darkly stained by leachate from streamside vegetation but are normally low in turbidity. The streams are sluggish, characterized by gentle gradients, and have naturally low dissolved oxygen (4.0-6.0 mg/L) during summer, making them unusually sensitive to increases in biochemical oxygen demand.

To understand how these waters respond to nutrient loading, we began conducting experiments to determine what effect inputs of nitrogen and phosphorus at levels typical of those in receiving streams would have on stream water quality. We collected water from blackwater rivers in swine-producing areas, distributed the water into 4-liter floatable plastic containers and added various nutrient treatments to the containers. We used ammonium as an inorganic nitrogen treatment, urea as an organic nitrogen treatment, orthophosphate as an inorganic phosphorus treatment, glycerophosphate as an organic phosphorus treatment, a combined ammonium plus orthophosphate treatment and a control of no nutrient inputs. The concentrations of nitrogen or phosphorus were 1.0 mg/L for each nutrient treatment.

The containers were incubated for six days outdoors in screen-covered pools and kept in motion by aquarium pumps. Periodically the containers were sampled to assess production of chlorophyll *a* and ATP, relative to control samples with no nutrient additions. Chlorophyll *a* is a measure of algal biomass, whereas ATP is a general measure of the biomass increase for all organisms in a sample.

In experiments conducted on water from the Black and Northeast Cape Fear Rivers, nitrogen additions mainly stimulated chlorophyll *a* concentrations (autotrophic organisms) whereas phosphorus additions only stimulated ATP production. When only ATP and not chlorophyll *a* is stimulated, it is likely that the heterotrophic community (bacteria, fungi and protozoans, rather than algae) is responsible for the ATP increase. Increases in heterotrophs directly increase the biochemical oxygen demand and lead to lower dissolved oxygen.

During subsequent experiments we demonstrated that nitrogen and phosphorus concentrations similar to those in Figure 10 can cause significant increases in oxygen demand in blackwater streams. Phytoplankton that bloom in shallow streams typically die and decompose upon entering deep, light-limited blackwater coastal-plain rivers, becoming yet another source of biochemical oxygen demand. These processes take place primarily during late spring and summer, when the water, being warm, holds less dissolved oxygen than it does during cooler seasons. The clustering of concentrated animal operations in certain geographic regions, particularly in basins of slow-flowing blackwater streams, puts these water bodies particularly at risk.

Animal-waste lagoons also have been shown to leak nutrients into nearby soils and groundwater. Groundwater may then enter streams or well water used for human consumption. A study of 11 unlined North Carolina swine-waste lagoons by Rodney L. Huffman and Philip Westerman of North Carolina State University in 1995 found that 55 percent demonstrated moderate to severe seepage losses of nitrogen. Average ammonia-nitrogen concentrations up to 1,000 mg/L and nitrate-nitrogen up to 50 mg/L were found in some wells near a clay-lined swine-waste lagoon on the Delmarva Peninsula (Ritter and Chinside 1990).

In a 1995 study in North Carolina, Westerman and his NCSU colleagues found ammonia-N concentrations up to 300 mg/L and nitrate-N up to 40 mg/L in wells downslope of unlined swine waste lagoons. Wells upslope of lagoons had ammonia-N concentrations of 0.2 mg/L or less and nitrate-N of 3.3 mg/L or less. Some of the studies concluded that higher seepage took place near lagoons on excessively well-drained soils, with less seepage from lagoons in poorly drained soils.

+ enlarge image

Thus, depending on local soil characteristics, some of this leakage can eventually find its way to surface water bodies through lateral transport by shallow groundwater. There is also a direct human health aspect to high nitrogen levels in groundwater. The U.S. Environmental Protection Agency's drinking-water standard for well water is 10 mg/L of nitrate or less, a limit designed to prevent an infant blood disorder known as "blue baby syndrome," or methemoglobinemia. In the body nitrate is reduced to nitrite, which converts hemoglobin to methemoglobin, making red blood cells unable to carry oxygen.

A Continual Influx of Nutrients

As a question of public policy, the growth of concentrated animal operations must be considered against the carrying capacity of the environments in which these operations are placed. Lawrence B. Cahoon, Jill A. Mickucki and I found (1999) that the amount of nitrogen and phosphorus in animal feed required to feed the 1995 swine, poultry and cattle population in the Cape Fear watershed came to approximately 100,000 tons of nitrogen and 33,000 tons of phosphorus. Over 90 percent of this input came into the watershed from other regions as far away as the Midwest, where feed is produced. More recently, Howard Glasgow and JoAnn Burkholder (in press) estimated that in 1998 animal operations in the nearby Neuse River basin required approximately 54,000 tons of nitrogen and 17,800 tons of phosphorus in feeds, of which 69 percent and 88 percent, respectively, were imported into the basin from elsewhere. These are staggeringly large quantities of "new" nutrients, of which about 75 percent remains in the watershed as animal waste in lagoons or on litterfields and sprayfields.

Of course nitrogen and phosphorus are traditionally taken up by crop plants, so some part of this input is potentially useful in the region's agriculture. It turns out to be a small part. The industrialization of swine production in North Carolina has been comparatively recent, but James C. Barker and Joseph P. Zublena of NCSU (1995) found that by 1993 three counties in North Carolina already generated more nitrogen and 18 counties more phosphorus in animal manure than could be utilized for the entire local crop production.

+ enlarge image

The 1997 Blue Ribbon Citizens Pfiesteria Action Commission report to the Governor of Maryland indicated that by 1991 the largest poultry-producing region in the state, the Southern Eastern Shore, was applying more phosphorus in manure to the crop fields than the crops could utilize. Soils in a number of areas rich in concentrated animal operations are accumulating excessive amounts of phosphorus. Phosphate is normally bound to soil particles and thus sequestered; however, when binding sites become saturated, excess phosphorus than may enter groundwater or nearby surface water bodies. This is particularly true when soils are sandy (as is typical in coastal plains) and well-drained or highly organic (Williams, Barker and Sims 1999). Over time, continual loading of animal wastes as liquid or litter saturates fields with nutrients, exacerbating eutrophication problems in surface-water supplies.

Industrial animal production facilities can also contribute nutrients to nearby waterways through atmospheric nitrogen deposition. Large amounts of the nitrogen applied to sprayfields is volatilized as ammonia, which becomes airborne and is deposited elsewhere. An example of an ammonia-producing area is Sampson County, North Carolina, an area of 946 square miles that with 1.8 million head was one of the nation's top swine-producing counties in 1998. The National Atmospheric Deposition Program (NADP) has monitored atmospheric ammonia at a Sampson County site since 1978. During the past 10 years there has been a concurrent rise in atmospheric ammonia and the swine population. Linear-regression analysis indicates that 72 percent of the variability in airborne ammonia can be explained by changes in the county swine population alone. Upwind in the North Carolina Piedmont, NADP sites in counties with low swine populations (Rowan and Wake) showed no ammonia increase over that same period.

The Outlook

Major pollution events caused by concentrated animal operations are by no means limited to one state or region. For example, in 1995 the Missouri Department of Natural Resources levied fines against pork producers for waste spills that caused the deaths of hundreds of thousands of fish in nearby waterways. The U.S. EPA and the Justice Department fined an Iowa producer for an illegal 1997 hog-waste discharge that killed more than 100,000 fish in a creek. Other hog-waste spills and consequent fish kills have occurred in Iowa as well (see Thu and Durrenberger 1998), and an August 1999 series of articles in *The Washington Post* documented substantial poultry-waste spills into waterways in Virginia and Delaware.

What is the prognosis for surface water resources in major swine- and poultry-producing areas? In 1993 the N.C. General Assembly promulgated regulations that mandated waste-management plans and clay liners for new waste lagoons. As a result of the 1995 and 1996 animal-waste incidents, in 1997 the General Assembly placed a two-year moratorium on new construction of concentrated animal operations; this moratorium was recently extended for another year. This legislative action also banned future building of hog houses and waste lagoons on the 100-year floodplain. However, new sprayfields were still permitted to be constructed and operated on the floodplain. Recently, the U.S. EPA has begun to address the problem. In a North Carolina case currently in litigation, EPA is arguing that livestock facilities that have discharged waste, including discharges from sprayfields, are required to apply for and obtain a National Pollution Discharge Elimination System (NPDES) permit.

+ enlarge image

Various management and technological strategies to reduce or better utilize the large amounts of waste generated by CAOs are currently being investigated at various locations such as N.C. State University's Animal and Poultry Waste Management Center. (For a review see Williams, Barker and Sims 1999.) One promising technique is enzyme (phytase) supplements in animal feeds to enhance digestion of phosphorus. This technique can result in significant decreases in the amount of phosphorus excreted by livestock. However, even with widespread use of this technology there still remain vast quantities of waste phosphorus to deal with, as well as much larger quantities of nitrogen. Per capita meat consumption in the developed world is not expected to grow over the next two decades; however, demand for pork and other meats is rapidly increasing and is expected to continue to grow in the Third World. With the expansion of industrial livestock production to areas such as the American West and South America, it is imperative that local communities anticipate potential environmental problems and design waste management and enforcement systems accordingly.

Acknowledgments

Funding for these research efforts was provided by the Lower Cape Fear River Program, the Water Resources Research Institute of the University of North Carolina (Project #s 70156 and 70171), and the Z. Smith Reynolds Foundation. Helpful manuscript criticism was provided by JoAnn M. Burkholder and Lawrence B. Cahoon. For field and laboratory assistance the author thanks David S. Briley, Nora Deamer-Melia, Scott H. Ensign, Howard B. Glasgow, Jr., Elle K. Hannon, Matthew R. McIver, Douglas C. Parsons, G. Christopher Shank, Ashley R. Skeen, Jeffrey R. Springer, Brant W. Touchette and Tracey L. Wheeler. The Wilmington and Raleigh offices of the N.C. Division of Water Quality provided much helpful information.

Bibliography

- Barker, J. C., and J. P. Zublena. 1995. Livestock manure assessment in North Carolina. In *Proceedings of the Seventh International Symposium on*

Agriculture and Food Processing Wastes. Washington, D.C.: American Society of Agricultural Engineers.

- Burkholder, J. M., and H. B. Glasgow, Jr. 1997. Pfiesteria piscicida and other Pfiesteria-like dinoflagellates: Behavior, impacts, and environmental controls. *Limnology and Oceanography* 42:1052–1075.
- Burkholder, J. M., M. A. Mallin, H. B. Glasgow, Jr., L. M. Larsen, M. R. McIver, G. C. Shank, N. Deamer-Melia, D. S. Briley, J. Springer, B. W. Touchette and E. K. Hannon. 1997. Impacts to a coastal river and estuary from rupture of a swine waste holding lagoon. *Journal of Environmental Quality* 26:1451–1466.
- Cahoon, L. B., J. A. Mickucki and M. A. Mallin. 1999. Nutrient imports to the Cape Fear and Neuse River basins to support animal production. *Environmental Science and Technology* 33:410–415.
- Delgado, C., M. Rosegrant, H. Steinfeld, S. Ehui and C. Courbois. 1999. *Livestock to 2020: The Next Food Revolution.* Food, Agriculture, and the Environment Discussion Paper 28. Washington, D.C.: International Food Policy Research Institute.
- Evans, R. O., P. W. Westerman and M. R. Overcash. 1984. Subsurface drainage water quality from land application of swine lagoon effluent. *Transactions of the American Society of Agricultural Engineers* 27:473–480.
- Gilliam, J. W., R. L. Huffman, R. B. Daniels, D. E. Buffington, A. E. Morey and S. A. Leclerc. 1996. *Contamination of Surficial Aquifers with Nitrogen Applied to Agricultural Land.* Report No. 306. Raleigh, N.C.: Water Resources Research Institute of the University of North Carolina.
- Glasgow, H. B. Jr., and J. M. Burkholder. In press. Water quality trends and management implications from a five-year study of a poorly flushed, eutrophic estuary. *Ecological Applications.*
- Hill, V. R., and M. D. Sobsey. 1998. Microbial indicator reductions in alternative treatment systems for swine wastewater. *Water Science and Technology* 38:119–122.
- Huffman, R. L., and P. W. Westerman. 1995. Estimated seepage losses from established swine waste lagoons in the lower coastal plain of North Carolina. *Transactions of the American Society of Agricultural Engineers* 38:449–453.
- Mallin, M. A., J. M. Burkholder, M. R. McIver, G. C. Shank , H. B. Glasgow, Jr., B. W. Touchette and J. Springer. 1997. Comparative effects of poultry and swine waste lagoon spills on the quality of receiving streamwaters. *Journal of Environmental Quality* 26:1622–1631.
- Mallin, M. A., L. B. Cahoon, D. C. Parsons and S. H. Ensign. 1998. *Effect of Organic and Inorganic Nutrient Loading on Photosynthetic and Heterotrophic Plankton Communities in Blackwater Rivers.* Report No. 315. Raleigh, N.C.: Water Resources Research Institute of the University of North Carolina.
- Mallin, M. A., M. H. Posey, G. C. Shank, M. R. McIver, S. H. Ensign and T. D. Alphin. 1999. Hurricane effects on water quality and benthos in the Cape Fear Watershed: Natural and anthropogenic impacts. *Ecological Applications* 9:350–362.
- Ritter, W. F., and A. E. M. Chirnside. 1990. Impact of animal waste lagoons on ground-water quality. *Biological Wastes* 34:39–54.
- Stone, K. C., P. G. Hunt, S. W. Coffey and T. A. Matheny. 1995. Water quality status of a USDA water quality demonstration project in the Eastern Coastal Plain. *Journal of Soil and Water Conservation* 50:567–571.
- Thu, K. M., and E. P. Durrenberger, eds. 1998. *Pigs, Profits, and Rural Communities.* Albany, N.Y.: State University of New York Press.
- Westerman, P. W., M. R. Overcash, R. O. Evans, L .D. King, J. C. Burns and C. A. Cummings. 1985. Swine lagoon effluent applied to 'coastal' bermudagrass: III. Irrigation and rainfall runoff. *Journal of Environmental Quality* 14:22–25.
- Williams, C. M., J. C. Barker and J. T. Sims. 1999. Management and utilization of poultry wastes. *Reviews in Environmental Contamination and Toxicology* 162:105–157.

EXHIBIT M

Prepared in cooperation with the North Carolina Department of Environment and Natural Resources, Division of Water Resources

Surface-Water Quality in Agricultural Watersheds of the North Carolina Coastal Plain Associated with Concentrated Animal Feeding Operations

Scientific Investigations Report 2015–5080

U.S. Department of the Interior
U.S. Geological Survey

Front and back covers: Sandy Run tributary to Middle Swamp, Greene County, North Carolina. Photographs by Stephen Harden, U.S. Geological Survey.

Surface-Water Quality in Agricultural Watersheds of the North Carolina Coastal Plain Associated with Concentrated Animal Feeding Operations

By Stephen L. Harden

Prepared in cooperation with the North Carolina Department of Environment and Natural Resources, Division of Water Resources

Scientific Investigations Report 2015–5080

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2015

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment—visit http://www.usgs.gov or call 1–888–ASK–USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit http://www.usgs.gov/pubprod/.

Suggested citation:
Harden, S.L., 2015, Surface-water quality in agricultural watersheds of the North Carolina Coastal Plain associated with concentrated animal feeding operations: U.S. Geological Survey Scientific Investigations Report 2015–5080, 55 p., 7 apps., http://dx.doi.org/10.3133/sir20155080.

ISSN 2328-0328 (online)

Acknowledgments

The research described in this report was partially funded by the U.S. Environmental Protection Agency's 319 grant program that is administered by the North Carolina Department of Environment and Natural Resources, Division of Water Resources. The author thanks Keith Larick (former employee), Ted Bush, Rick Bolich, Michael Tutwiler, and Kim Nimmer of the North Carolina Department of Environment and Natural Resources for their help and support in this project. Appreciation is extended to the private landowners in eastern North Carolina who graciously allowed access to their property. This study would not have been possible without the help of U.S. Geological Survey personnel who assisted with sample collections and (or) data compilations, including Brian Pointer, Ryan Rasmussen, Sean Egen, Jessica Cain, Katharine Kolb, and Dominick Antolino. Finally, gratitude is extended to Thomas Cuffney, J.K. Böhlke, and Kristen McSwain, U.S. Geological Survey, for providing valuable technical discussions during the study, and to Judith Denver, Mary Giorgino, and Stephen Kalkhoff, U.S. Geological Survey, who provided many helpful review comments and suggestions on the report manuscript.

Contents

Figures

Tables

Appendixes (available at http://pubs.usgs.gov/sir/2015/5080/)

Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
million gallons (Mgal)	3,785	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)
pound avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	megagram (Mg)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as
°F = (1.8 × °C) + 32.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter (µg/L).

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Abbreviations

AFO	animal feeding operation
ANOVA	analysis of variance
BK sites	background watersheds with no active CAFOs
CAFO	concentrated animal feeding operation
DO	dissolved oxygen
DWR	North Carolina Division of Water Resources
EPA	U.S. Environmental Protection Agency
GIS	geographic information system
GMWL	global meteoric water line
HSG	hydrologic soil group
lidar	light detection and ranging
LMWL	local meteoric water line
N	nitrogen
NLCD	National Land Cover Database
NPDES	National Pollutant Discharge Elimination System
NPS	nonpoint source
NWIS	USGS National Water Information System
NWQL	USGS National Water Quality Laboratory
ortho-P	orthophosphate
P	phosphorus
PAN	plant available nitrogen
RL	reporting level
RPD	relative percent difference
RSIL	USGS Reston Stable Isotope Laboratory
SP sites	watersheds with at least one active swine CAFO and one active poultry CAFO
SSLW	steady state live weight
SW sites	watersheds with one or more active swine CAFOs but no poultry CAFOs
USGS	U.S. Geological Survey

Surface-Water Quality in Agricultural Watersheds of the North Carolina Coastal Plain Associated with Concentrated Animal Feeding Operations

By Stephen L. Harden

Abstract

The effects of concentrated animal feeding operations (CAFOs) on water quality were investigated at 54 agricultural stream sites throughout the North Carolina Coastal Plain during 2012 and 2013. Three general watershed land-use types were examined during the study, including 18 background watersheds with no active CAFOs (BK sites), 18 watersheds with one or more active swine CAFOs but no poultry CAFOs (SW sites), and 18 watersheds with at least one active swine CAFO and one active dry-litter poultry CAFO (SP sites). The watershed drainage areas for these 54 stream sites ranged from 1.2 to 17.5 square miles. Conventional fertilizers used for crop production are the primary source of nutrients at the BK sites. Animal-waste manures represent an additional source of nutrients at the SW and SP study sites.

Land cover, soil drainage, and CAFO attributes were compiled for each watershed. Water-quality field measurements were made and samples were collected at the 54 primary sites during 6 bimonthly sampling periods from June 2012 to April 2013. An additional 23 secondary sites were sampled once during April 2013 to provide supplemental data at stream locations directly adjacent or in close proximity to swine CAFOs and (or) background agricultural areas within 9 of the primary watersheds. The watershed drainage areas for the 23 secondary sites ranged from 0.2 to 8.9 square miles. Water temperature, specific conductance, dissolved-oxygen concentration, and pH were measured directly in the streams. Water samples were analyzed for major ions, nutrients, and stable isotopes, including delta hydrogen-2 (δ^2H) and delta oxygen-18 ($\delta^{18}O$) of water and delta nitrogen-15 ($\delta^{15}N$) and $\delta^{18}O$ of dissolved nitrate plus nitrite.

Most of the water-quality properties and constituents varied significantly among the six sampling periods, changing both seasonally and in response to hydrologic conditions. The differences noted among the sampling periods indicate that the interactions between seasonal climatic differences, streamflow conditions, and instream biotic and abiotic processes are complex and their integrated effects can have varying degrees of influence on individual nutrients.

Water-quality differences were noted for the SW and SP land-use groups relative to the BK group. Median values of specific conductance, several major ions (magnesium, sodium, potassium, and chloride), and nitrogen fractions (ammonia plus organic nitrogen, ammonia, nitrate plus nitrite, total nitrogen, and $\delta^{15}N$ of nitrate plus nitrite) were higher for the SW and SP groups compared to the BK group. No significant differences in water temperature, dissolved oxygen, calcium, total organic nitrogen, orthophosphate, total phosphorus, or $\delta^{18}O$ of nitrate plus nitrite were noted among the land-use groups. When compared on the basis of land-use type, there was an overall measurable effect of CAFO waste manures on stream water quality for the SW and SP watershed groups.

Some individual sites within the SW and SP groups showed no measurable CAFO effects on water quality despite having CAFOs present upstream. An evaluation of sodium plus potassium concentrations coupled with $\delta^{15}N$ values of nitrate plus nitrite proved valuable for distinguishing which SW and SP sites had a water-quality signature indicative of CAFO waste manures. Sites with CAFO manure effects were characterized by higher sodium plus potassium concentrations (commonly between 11 and 33 milligrams per liter) and $\delta^{15}N$ values of nitrate plus nitrite (commonly between 11 and 26 parts per thousand) relative to sites reflecting background agricultural conditions, which commonly had sodium plus potassium concentrations between 6 and 14 milligrams per liter and $\delta^{15}N$ values of nitrate plus nitrite between 6 and 15 parts per thousand. On the basis of the results of this study, land applications of waste manure at swine CAFOs influenced ion and nutrient chemistry in many of the North Carolina Coastal Plain streams that were studied.

A classification tree model was developed to examine relations of watershed environmental attributes among the study sites with and without CAFO manure effects. Model results indicated that variations in swine barn density, percentage of wetlands, and total acres available for applying swine-waste manures had an important influence on those watersheds where CAFO effects on water quality were either evident or mitigated. Measurable effects of CAFO waste manures on stream water quality were most evident in those SW and SP watersheds having lower percentages of wetlands combined

with higher swine barn densities and (or) higher total acres available for applying waste manure at the swine CAFOs. Stream water quality was similar to background agricultural conditions in SW and SP watersheds with lower swine barn densities coupled with higher percentages of wetlands or lower acres available for swine manure applications. The model provides a useful tool for exploring and identifying similar, unmonitored watersheds in the North Carolina Coastal Plain with potential CAFO manure influences on water quality that might warrant further examination.

Introduction

The U.S. Environmental Protection Agency's (EPA) National Water Quality Inventory Report to Congress (U.S. Environmental Protection Agency, 2010) lists pathogens, sediment, organic enrichment and oxygen depletion, and nutrients as several leading causes of impairment of rivers and streams in the United States. Agriculture, including crop and animal production, was cited as the most probable source of impairments in the assessed rivers and streams. Nonpoint-source (NPS) pollution from agricultural activities is of particular concern in eastern North Carolina because nutrient over-enrichment in surface waters has contributed to water-quality problems in the Tar-Pamlico, Neuse, and Cape Fear River Basins, particularly in the estuaries (Spruill and others, 1998; Luettich and others, 2000; Burkholder and others, 2006). Excessive inputs of nitrogen (N) and phosphorus (P) to nutrient-sensitive waters can contribute to eutrophication, excess algal blooms, fish kills, and outbreaks of toxic dinoflagellates (Burkholder and others, 1995; Burkholder and Glasgow, 1997; Stow and others, 2001; Paerl and others, 2004). Animal feeding operations (AFOs) are recognized as important NPS contributors of N and P to streams in the North Carolina Coastal Plain physiographic province (Glasgow and Burkholder, 2000; Mallin and Cahoon, 2003; Burkholder and others, 2006; Rothenberger and others, 2009). Large amounts of land-applied animal manures in watersheds with high densities of AFOs can lead to nutrient surpluses that exceed the assimilative capacity of the watershed to absorb excess nutrients without having deleterious effects on water quality (Stone and others, 1998; Mallin and Cahoon, 2003; Hubbard and others, 2004; Sims and others, 2005; Copeland, 2010).

North Carolina is one of the Nation's leading animal producers, ranking second in the production of both swine and turkeys and fourth in the production of broiler chickens (North Carolina Department of Agriculture and Consumer Services, 2012). In North Carolina, AFOs are regulated and permitted as non-discharge facilities by the Animal Feeding Operations Program within the North Carolina Department of Environment and Natural Resources Division of Water Resources (DWR). As of January 2013, there were 2,356 individually permitted AFOs in North Carolina (North Carolina Division of Water Resources, 2013), with about 90 percent of the facilities consisting of swine AFOs (total of 2,132) and the remaining 10 percent consisting primarily of cattle (total of 199) and wet poultry (total of 21) AFOs. The majority of the swine AFOs (2,006) are located in the Coastal Plain (fig. 1). Most poultry AFOs in North Carolina consist of dry-litter operations that are exempt from permitting by the State. The number of dry-litter poultry AFOs in the Coastal Plain is likely similar to the number of swine AFOs (Keith Larick, North Carolina Division of Water Resources, oral commun., June 2013).

It is of note that the terms AFO and concentrated animal feeding operation (CAFO) often are used interchangeably within the literature; however, there are technical distinctions between them as defined by the EPA (40 CFR §122.23). The EPA generally defines AFOs as "operations where animals have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12-month period and where vegetation is not sustained in the confinement area during the normal growing season" (U.S. Environmental Protection Agency, 2012). An AFO may be further designated as a CAFO on the basis of the number of animals confined and specific criteria concerning the discharge of pollutants to adjacent surface waters, which if so designated makes the CAFO subject to National Pollutant Discharge Elimination Systems (NPDES) permitting requirements (40 CFR §122.23). In this report, swine and poultry feeding operations are collectively referred to as CAFOs even though they may not all technically meet the regulatory definitions.

At a typical swine CAFO, waste materials are flushed from the swine houses to one or more holding lagoons for temporary storage. Wastewater effluent from the lagoon(s) periodically is applied to nearby fields, commonly through surface spraying, in accordance with the permitted facility's Certified Animal Waste Management Plan such that the total N applied can be used during crop growth to avoid runoff or excessive leaching (Keith Larick, North Carolina Division of Water Resources, oral commun., June 2013); however, problems can result from adverse weather conditions or application rates that exceed crop uptake (Evans and others, 1984; Smith and Evans, 1998). At the poultry CAFOs, dry litter commonly is applied to cropland at the individual facilities if sufficient acreage is available, or the litter can be transported offsite and applied as a source of nutrients to other agricultural fields (Crouse and Shaffer, 2011).

Previous studies have examined the effects of swine and poultry CAFOs on groundwater and surface-water quality, especially regarding N and P, in the North Carolina Coastal Plain. Huffman (2004) found that seepage from swine-waste lagoons built before 1993, without clay liners, increased shallow groundwater concentrations of mineral N (ammonia N plus nitrate N) by 10 to 40 milligrams per liter (mg/L) as N at 11 sites and more than 40 mg/L as N at 16 sites. Various investigators have noted nitrate concentrations commonly between 10 and 30 mg/L, and in some cases between 50 and 150 mg/L, in groundwater collected beneath or adjacent to application fields receiving swine-lagoon effluent or

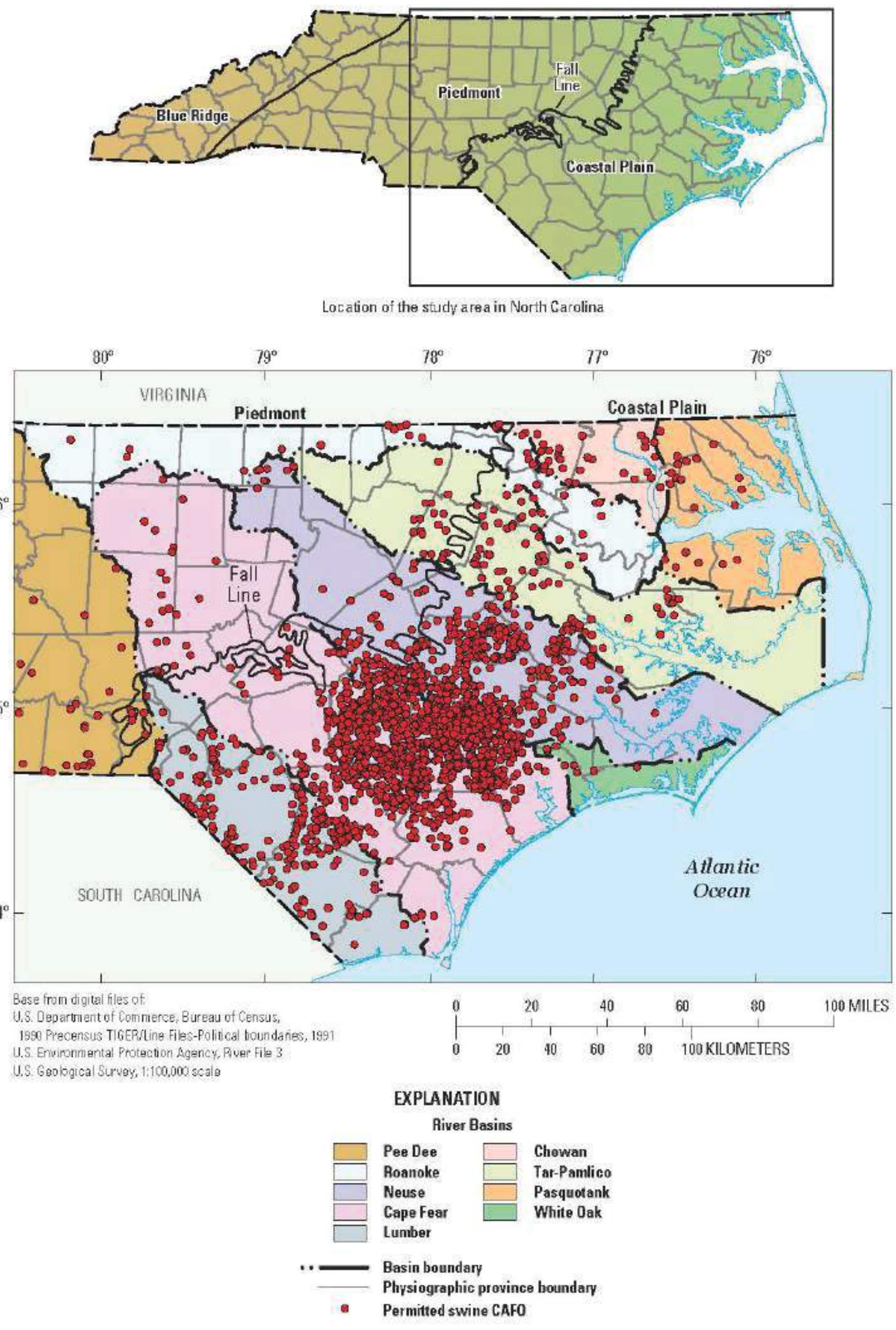


Figure 1. Locations of permitted swine concentrated animal feeding operations (CAFOs) in eastern North Carolina (swine CAFO locations obtained from North Carolina Division of Water Resources, 2013).

poultry litter (Hunt and others, 1995; Stone and others, 1998; Karr and others, 2001; Spruill and others, 2002; Israel and others, 2005; Dukes and Evans, 2006; Harden and Spruill, 2008). In addition to nitrate, increased concentrations of calcium, magnesium, sodium, potassium, and chloride have been observed in groundwater beneath swine CAFO spray fields (Karr and others, 2001; Spruill and others, 2005). The transport of P from agricultural fields to surface water typically occurs through overland runoff; however, repeated applications of swine-waste manure to fields can lead to excess accumulations of P in soil and subsequent leaching to groundwater for possible offsite transport to receiving streams (Novak and others, 2000; Nelson and others, 2005).

Elevated nutrient concentrations also have been observed in streams receiving overland runoff, groundwater discharge, and subsurface tile drainage derived from CAFOs (Stone and others, 1995; Karr and others, 2001; Spruill and others, 2005; Dukes and Evans, 2006; Harden and Spruill, 2008). Stone and others (1995) noted that a stream with intensive swine and poultry operations had nutrient concentrations during both stormflow and baseflow conditions that were several times higher than those in an adjacent background stream with no animal operations. In the stream influenced by the CAFOs, mean concentrations were 5.6 mg/L as N for nitrate, 0.74 mg/L as N for ammonia, and 0.68 mg/L for orthophosphate during baseflow conditions, and mean concentrations were 5.4 mg/L as N for nitrate, 2.28 mg/L as N for ammonia, and 1.3 mg/L for orthophosphate during stormflow conditions. Surface-water samples collected by Karr and others (2001) in a stream adjacent to two swine CAFOs had a median nitrate concentration of 6.7 mg/L as N. Harden and Spruill (2008) observed elevated levels of nitrate (median of 6.1 and range of 2.0 to 10.7 mg/L as N), ammonia (median of 0.76 and range of 0.09 to 2.38 mg/L as N), and dissolved P (median of 0.05 and range of 0.01 to 0.29 mg/L) in 28 surface-water samples collected in 2006 during stormflow and baseflow conditions from a stream next to waste-manure application fields at a swine CAFO. Elevated nitrate concentrations in this stream are considered to be strongly influenced by water discharged through a tile drain located in one of the adjacent spray fields (Spruill and others, 2005, Harden and Spruill, 2008). In 2006, water discharging from the tile drain to the stream had nitrate concentrations ranging from about 22 to 45 mg/L as N (Harden, 2008).

The practice of applying waste manure to fields at swine CAFOs is common in many watersheds throughout the Coastal Plain so there is substantial interest in understanding their influence on stream water quality. Many of the studies conducted to evaluate water-quality conditions related to CAFOs in the Coastal Plain have been limited in geographic extent, either focusing on individual farm sites or several streams within a particular watershed. The lack of stream water-quality data from a more representative number of watersheds makes it difficult for DWR to assess the extent to which effects of swine CAFOs on surface-water quality can be measured and how well existing CAFO regulations protect the waters of the State or to recommend effective changes to regulations or procedures. In 2011, DWR (formerly named the Division of Water Quality) and the U.S. Geological Survey (USGS) initiated a collaborative study to document whether swine CAFOs located in various Coastal Plain watersheds have a measurable effect on stream water quality. The study results presented in this report provide needed information from a large number of sites over a broader geographic area to better understand relations between swine CAFOs and stream water quality in eastern North Carolina.

Purpose and Scope

The primary purpose of this report is to summarize and synthesize chemical data collected from 54 agricultural watershed study sites throughout the North Carolina Coastal Plain to characterize water-quality conditions in streams receiving inputs from swine CAFOs compared to streams that receive inputs primarily from inorganic fertilizers. The scope of work included field measurements of water-quality properties and collection of surface-water samples for laboratory analysis of nutrients, major ions, and stable isotopes. Six rounds of bimonthly samples were collected from June 2012 to April 2013 at 54 primary watershed study sites. The last sampling round in April 2013 included collection and analysis of samples from 23 additional sites located within 9 of the 54 primary watersheds. Results were used to evaluate differences in stream water quality among watersheds with no CAFOs, watersheds with swine CAFOs, and watersheds with both swine and poultry CAFOs. Land cover, soil drainage class, and CAFO attributes (such as number of facilities, animal barns, swine animals, and total weight of swine) were used to examine potential relations between watershed environmental variables and water-quality conditions among the primary study sites. The main study objectives were to (1) assess water-quality differences among streams draining watersheds with and without land-applied CAFO waste manures, (2) examine the use of multiple chemical constituents for identifying effects of CAFOs on stream water quality, and (3) examine relations of environmental variables among watersheds with and without measurable CAFO manure effects. The study results are intended to assist water-resource managers and policy makers in their efforts to protect and improve stream water quality throughout North Carolina.

Description of the Study Area

The watershed sites examined in the Coastal Plain study area have drainage areas less than 20 square miles (mi^2) with land cover composed predominantly of cropland, forests, and wetlands. Most of the watersheds typically feature low-gradient blackwater streams and swamps with slow streamflow velocities. Varying degrees of submerged and floating aquatic vegetation and organic debris are present within and along the stream channels. These types of streams often have naturally low dissolved oxygen (DO) that can be depleted further as a result of nutrient and organic inputs from agricultural activities.

When examining stream water quality at the agricultural watershed sites in this study, it is important to understand that different processes influence fate and transport of nutrient inputs from agricultural fields to receiving streams. Nutrients applied to agricultural fields that percolate through the soils to the underlying surficial aquifer can be transported with groundwater as it discharges to receiving streams. Hydrograph separations performed on streamflow data during previous investigations indicate that groundwater, thought to be derived mostly from shallow aquifer systems, commonly contributes about 50 to 60 percent of the average annual streamflow to streams in the North Carolina Coastal Plain (McMahon and Lloyd, 1995; Spruill and others, 2005; Harden and others, 2013). Therefore, groundwater is potentially a major contributor of water and agriculturally derived chemical constituents to the stream study sites, particularly when there is minimal overland runoff from precipitation.

Various environmental, hydrogeologic, and geochemical factors that influence nitrate transport along groundwater flow paths beneath agricultural fields to receiving streams in the North Carolina Coastal Plain are discussed by Spruill and others (2005) and Harden and Spruill (2008). These factors include depth to water and saturated thickness of the surficial aquifer (Tesoriero and others, 2000; Tesoriero and others, 2005), groundwater residence times (Puckett, 2004; Tesoriero and others, 2005; Seitzinger and others, 2006), availability of organic carbon to drive denitrification reactions (Korom, 1992), and presence of riparian buffers (Speiran and others, 1998; Spruill, 2000; Puckett, 2004; Seitzinger and others, 2006). In evaluating changes in nitrate concentrations along groundwater flow paths at five study sites in the Coastal Plain, Harden and Spruill (2008) determined that denitrification was the most influential factor responsible for observed decreases in groundwater nitrate along the flow paths. Although some denitrification of groundwater nitrate occurred beneath the agricultural fields, nitrate reduction along the groundwater flow paths was most prevalent in the downgradient riparian buffer zone and hyporheic zone at the streams, where highly reduced conditions associated with organic-rich deposits enhanced the overall amount of denitrification.

The nitrate-reducing capacity of the buffer zone combined with that of the hyporheic zone can substantially lower the amount of groundwater nitrate discharged to streams in agricultural settings of the Coastal Plain (Spruill, 2000; Harden and Spruill, 2008). Depending on hydrogeologic and geochemical conditions, relatively young groundwater may move quickly along shallow flow paths beneath the riparian buffer and outpace the time needed for complete reduction of nitrate before discharging to a stream. Groundwater discharge along shallow flow paths may occur along seeps or channel walls that bypass the highly organic fluvial material in the hyporheic zone. If this water contains nitrate that has passed through the riparian buffer, the water can affect the nitrate concentration in the receiving stream.

In addition to groundwater transport, overland flow of water that occurs through field-drainage ditches is another important pathway that conveys nutrients from agricultural fields to receiving streams. Field-drainage ditches and subsurface tile drains commonly are used in the North Carolina Coastal Plain for improving drainage in agricultural fields with poorly drained soils (Evans and others, 1991; Gilliam and others, 1997). Water conveyed through the field ditches to the streams includes surface runoff from the fields, when rainfall amounts are greater than the infiltration capacity of soils, and subsurface inputs of shallow groundwater from beneath the fields. Lateral inflows of shallow groundwater through the banks and bottom of the ditches can occur during parts of the year when high water-table conditions are present beneath the fields. In fields with subsurface tile drains, shallow groundwater intercepted and collected by the tiles at the top of the water table is discharged through outlets directly to the ditches.

These drainage improvements lower the water table beneath agricultural fields, which increases the amount of land available for cultivation; however, the process of redirecting shallow groundwater beneath agricultural fields through tile drains and ditches can increase nutrient transport, particularly nitrate, in drainage water exiting the fields to receiving streams (David and others, 1997; Jaynes and others, 2001; Randall and Mulla, 2001; Harden and Spruill, 2004). As previously discussed, elevated nitrate concentrations in shallow groundwater beneath agricultural fields have commonly been observed in the Coastal Plain, especially at fields receiving land applications of animal-waste manures. A study by Harden and Spruill (2004) on the quality of drainage water from field ditches and tile drains in a North Carolina Coastal Plain watershed found that median concentrations of nitrate as N were significantly higher in water exiting field ditches (8.2 mg/L) and tile drains (32.0 mg/L) at fields receiving applications of swine-waste manures as compared to field ditches (2.7 mg/L) and tile drains (6.8 mg/L) at fields receiving applications of commercial fertilizers.

Because field ditches and tile drains are used to expedite the drawdown of the water table, they can allow groundwater with elevated nitrate levels in the upper part of the surficial aquifer beneath agricultural fields to bypass natural organic-rich aquifer sediments in the riparian buffer and hyporheic zones that normally would reduce the amount of nitrate in groundwater discharging to the streams (Spruill, 2000; Harden and Spruill, 2008). Considering that most watersheds examined for this study have substantial riparian buffer zones and organic-rich floodplain deposits and, hence, a high degree of denitrification potential prior to groundwater discharge, it is probable that overland inputs of water through field drainage ditches contribute much of the nitrate delivered to the stream sites. Overland transport through the field ditches can occur anytime there is excessive runoff from storm events but is most common during sustained periods of high water-table conditions, which typically occur during the colder winter and early spring months, generally from December to April, when evapotranspiration is lowest.

Methods

This section provides a discussion of the network design and watershed attributes compiled for the study sites, and the sampling and analytical methods used for generating the water-quality dataset. Statistical methods used during data analysis also are discussed.

Network Design and Watershed Attributes

An integrated approach was used for establishing the network of surface-water sampling sites for the study. Three general watershed land-use types, or groups, were included: watersheds with no active CAFOs (referred to as background (BK) sites); watersheds with one or more active swine CAFOs but no poultry CAFOs (referred to as SW sites); and watersheds with at least one active swine CAFO and one active poultry CAFO (referred to as SP sites). Although the initial study intent was to evaluate potential influences of swine CAFOs, it was difficult to find swine only watersheds across the study area that did not also contain poultry CAFOs. Therefore, the SP sites were included to provide data for additional watersheds containing swine CAFOs, as well as for examining potential differences between swine only sites and sites with both swine and poultry. Watersheds that contained only poultry CAFOs were not considered because it was outside the scope of work for this study.

The stream sites selected for study include an equal number (18) representing each of the BK, SW, and SP watershed land-use types (table 1; fig. 2) that also had similar distributions in watershed characteristics such as drainage areas and land cover. These 54 watershed sites are referred to as primary study sites because they were the primary focus of data-collection activities for the 6 bimonthly sampling periods from June 2012 to April 2013. The April 2013 sampling period included collection of surface-water samples from 23 additional sites, referred to as secondary sites, located within 9 of the primary watershed sites (table 1). One or more secondary sites were sampled upstream from the primary sites to provide additional water-quality data for stream sites located close or adjacent to swine CAFOs and (or) in subwatershed areas with no swine CAFOs. The study network spanned six river basins throughout the Coastal Plain in eastern North Carolina (table 1; fig. 2). Individual maps for the primary and secondary sites are provided in appendix A1 (figs. A1-1 through A1-54).

All study watersheds have than less than 10 percent developed (urban) lands, and none contain permitted NPDES wastewater-discharge facilities. Therefore, agricultural activities represent the most likely source of nutrients to the streams. The watersheds without CAFOs (BK sites) and with CAFOs (SW and SP sites) all contain agricultural lands where commercial fertilizers are used during the production of crops. The water-quality constituents analyzed in stream samples collected during the study include those essential primary nutrients (N, P, and potassium) and secondary nutrients (calcium, magnesium, and sulfur) found in commercial fertilizer materials commonly used in North Carolina for growing crops (Zublena and others, 1991; Tucker, 1999). These same essential plant nutrients, as well as sodium and chloride, are found in swine and poultry organic waste manures (Zublena and others, 1991, 1997a, 1997b; Barker and others, 1994; Osmond and Kang, 2008). Land applications of swine-waste manure and poultry litter represent an additional source of these constituents to agricultural fields in the SW and SP watersheds. Because watershed characteristics are similar among the three site groups, with the exception of the presence or absence of CAFOs, differences in stream concentrations of nutrients and (or) major ions observed at the SW and SP sites relative to the BK sites likely reflect inputs derived from swine and (or) poultry animal-waste manures.

Watershed boundaries and contributing drainage areas for the study sites were determined using the USGS StreamStats application developed for North Carolina (http://water.usgs.gov/osw/streamstats/north_carolina.html; Weaver and others, 2012). These features were calculated within StreamStats using a 30-foot (ft) by 30-ft lidar-derived digital elevation model (North Carolina Floodplain Mapping Program, 2012). Watershed drainage areas range from 1.2 to 17.5 mi^2 for the 54 primary sites and 0.2 to 8.9 mi^2 for the 23 secondary sites.

Data were compiled for selected watershed attributes to characterize environmental conditions at the study sites. Physical (land cover and soil drainage) and anthropogenic features (point-source dischargers, non-discharge land application sites, and CAFOs) were compiled using geographic information system (GIS) processes. The 54 primary sites were chosen to avoid or minimize potential influences of wastewater-discharge facilities, non-discharge facilities, and developed lands in order to facilitate water-quality interpretations between the watersheds with and without CAFOs.

Table 1. Study network, including primary and associated secondary sites, monitored for water quality in the North Carolina Coastal Plain.

[ID, identification; HUC, hydrologic unit code; USGS, U.S. Geological Survey; NC, North Carolina; HWY, highway; SR, secondary road; mi², square miles]

Primary study ID (see fig. 2)	Secondary study ID associated with primary sites (see appendix A1)	River basin	USGS station number	USGS station name	Decimal latitude	Decimal longitude	Drainage area (mi^2)
BK-01		Roanoke	0208102325	Blue Hole Swamp at NC HWY 11/42 near Cahaba, NC	36.01654	–77.21197	14.9
BK-02		Roanoke	02081065	Smithwick Creek near Bear Grass, NC	35.76589	–77.05184	12.5
BK-03		Roanoke	02081040	Etheridge Swamp at SR 1326 near Oak City, NC	35.98837	–77.34820	3.9
BK-04		Roanoke	0208103875	Conoho Creek at SR 1336 near Oak City, NC	36.01207	–77.29780	10.0
BK-05		Roanoke	0208105040	Conoho Creek tributary at SR 1002 at Hassell, NC	35.91971	–77.27077	10.8
BK-06		Chowan	0205309110	Kirbys Creek tributary at SR 1356 near Pendleton, NC	36.49604	–77.17341	5.9
BK-07		Tar-Pamlico	02083583	Williamson Branch at SR 1128 near St. Lewis, NC	35.79453	–77.72893	4.5
BK-08		Tar-Pamlico	02083889	Tyson Creek at SR 1245 at Kings Crossroads, NC	35.65818	–77.55068	3.8
BK-09		Tar-Pamlico	02084212	Hunting Run near Pactolus, NC	35.66947	–77.26106	5.9
BK-10		Tar-Pamlico	0208451810	Beaverdam Swamp at SR 1520 near Alligoods, NC	35.55525	–76.92182	5.5
BK-11		Neuse	02090770	Whiteoak Swamp at SR 1514 near Holdens Crossroads, NC	35.70709	–77.75435	5.6
BK-12		Neuse	0209096970	Moccasin Run near Patetown, NC	35.47927	–77.90992	3.1
BK-13		Neuse	02091623	Langs Mill Run at SR 1242 near Fountain, NC	35.64908	–77.60427	5.9
BK-14		Neuse	02091712	Middle Swamp near Marlboro, NC	35.56626	–77.59853	14.7
BK-15		Cape Fear	0210682145	Big Creek at SR 1006 at Bethany Crossroads, NC	35.05978	–78.70102	6.1
BK-16		Cape Fear	0210591785	Sevenmile Swamp at US HWY 13 at Rosin Hill, NC	35.20431	–78.43143	9.2
BK-17		Cape Fear	0210754615	White Oak Branch at SR 1209 near Ivanhoe, NC	34.61149	–78.18248	3.9
BK-18		Lumber	0213453011	Horse Swamp at SR 2435 near Fairmont, NC	34.52107	–79.17844	5.4
SW-01		Roanoke	02081016	Steptoe Run near Scotland Neck, NC	36.10934	–77.37070	5.4
SW-02		Tar-Pamlico	02083686	Kitten Creek at SR 1251 near Sharp Point, NC	35.70728	–77.56920	9.0
SW-03		Tar-Pamlico	0208368850	Unnamed tributary to Otter Creek at SR 1615 near Sharp Point, NC	35.73388	–77.57359	4.8
SW-04		Neuse	02089225	Little Marsh Run at SR 1714 at Parkstown, NC	35.37789	–77.82240	1.2
	SW-04A	Neuse	0208922490	Little Marsh Run headwaters near Parkstown, NC	35.38754	–77.83183	0.4
	SW-04B	Neuse	0208922495	Little Marsh Run at St. Delight Ch. Road at Parkstown, NC	35.38270	–77.82576	1.0
SW-05		Neuse	02089584	Hornpipe Branch at SR 1130 near Deep Run, NC	35.14308	–77.66903	3.9
	SW-05A	Neuse	0208958380	Hornpipe Branch at SR 1137 near Deep Run, NC	35.13115	–77.66361	0.8
	SW-05B	Neuse	0208958385	Hornpipe Branch tributary at SR 1137 near Deep Run, NC	35.13326	–77.65996	0.5
	SW-05C	Neuse	0208958390	Hornpipe Branch tributary at SR 1130 near Deep Run, NC	35.13682	–77.66893	0.9
SW-06		Neuse	02091960	Creeping Swamp near Calico, NC	35.42944	–77.18974	11.2
SW-07		Neuse	02090793	Whiteoak Swamp tributary at SR 1514 at Drivers Store, NC	35.70027	–77.81418	1.3
SW-08		Neuse	02091725	Sandy Run at US HWY 13/258 at Lizzie, NC	35.51625	–77.61542	15.8
	SW-08A	Neuse	0209172000	Sandy Run at SR 1301 near Castoria, NC	35.53175	–77.65237	8.9
	SW-08B	Neuse	0209172150	Drainage ditch to Sandy Run at SR 1326 near Lizzie, NC	35.51573	–77.65001	1.2
	SW-08C	Neuse	02091722	Unnamed tributary to Sandy Run at SR 1301 near Lizzie, NC	35.52024	–77.64036	2.8
	SW-08D	Neuse	02091724	Unnamed tributary to Sandy Run at SR 1301 at Lizzie, NC	35.51052	–77.62631	1.2

Table 1. Study network, including primary and associated secondary sites, monitored for water quality in the North Carolina Coastal Plain.—Continued

[ID, identification; HUC, hydrologic unit code; USGS, U.S. Geological Survey; NC, North Carolina; HWY, highway; SR, secondary road; mi², square miles]

Primary study ID (see fig. 2)	Secondary study ID associated with primary sites (see appendix A1)	River basin	USGS station number	USGS station name	Decimal latitude	Decimal longitude	Drainage area (mi²)
SW-09		Cape Fear	0210596803	Hornet Swamp at SR 242 near Piney Green, NC	35.11474	–78.47670	4.0
SW-10		Cape Fear	0210592050	Ward Swamp at SR 1711 near Monks Crossroads, NC	35.19976	–78.30362	1.3
SW-11		Cape Fear	0210770367	Youngs Swamp at SR 1725 near Giddensville, NC	35.16676	–78.21747	2.1
SW-12		Cape Fear	0210778920	Big Branch at SR 1301 at Bowdens, NC	35.06026	–78.10009	3.2
SW-13		Cape Fear	0210782015	King Branch at SR 1305 at Friendship, NC	35.06047	–78.04184	1.9
	SW-13A	Cape Fear	0210782010	King Branch Headwaters near Friendship, NC	35.06601	–78.06513	0.8
	SW-13B	Cape Fear	0210782013	King Branch Headwaters at Friendship, NC	35.06814	–78.05202	1.2
SW-14		Lumber	0213449620	Rattlesnake Branch at SR 1516 at Lennons Crossroads, NC	34.47430	–78.85823	3.1
SW-15		Lumber	0213453155	Aaron Swamp at SR 2455 near McDonald, NC	34.51163	–79.20262	12.1
SW-16		Lumber	0210899420	Little Whites Creek at SR 1700 near Bluefield, NC	34.54721	–78.61481	3.6
SW-17		Lumber	0210899878	Horseshoe Swamp at SR 1713 near Lisbon, NC	34.50059	–78.53169	9.4
SW-18		Lumber	0210910290	Butler Branch at US HWY 701 near Wootens Crossroads, NC	34.44726	–78.72026	3.7
SP-01		Tar-Pamlico	02084148	Chicod Creek at SR 1565 near Grimesland, NC	35.53304	–77.18784	17.5
	SP-01A	Tar-Pamlico	0208414580	Chicod Creek tributary at SR 1782 at Boyds Crossroads, NC	35.51606	–77.19316	1.6
	SP-01B	Tar-Pamlico	0208414590	Chicod Creek tributary south of SR 1780 at Boyds Crossroads, NC	35.52571	–77.18306	2.0
	SP-01C	Tar-Pamlico	0208414750	Chicod Creek tributary north of SR 1780 at Boyds Crossroads, NC	35.53302	–77.18058	0.5
SP-02		Neuse	0208813655	White Oak Branch at SR 1144 near Strickland Crossroads, NC	35.34614	–78.37521	5.3
SP-03		Neuse	02088285	Thoroughfare Swamp near Dobbersville, NC	35.23844	–78.15107	14.3
SP-04		Neuse	0208831520	Falling Creek at SR 1102 near Dobbersville, NC	35.27517	–78.27242	3.7
	SP-04A	Neuse	0208831504	Falling Creek tributary at SR 1201 near Newton Grove, NC	35.28633	–78.29202	0.4
	SP-04B	Neuse	0208831510	Falling Creek tributary at US HWY 13 near Newton Grove, NC	35.27540	–78.28327	1.5
SP-05		Neuse	02089598	Unnamed tributary to Southwest Creek at NC HWY 11 near Albrittons, NC	35.18177	–77.67071	1.4
	SP-05A	Neuse	0208959780	Southwest Creek tributary 2 at SR 1159 near Albrittons, NC	35.18384	–77.67951	0.5
	SP-05B	Neuse	0208959790	Southwest Creek tributary at SR 1159 near Albrittons, NC	35.17731	–77.67791	0.4
SP-06		Cape Fear	02105702	Davis Creek at SR 1713 near Lisbon, NC	34.54040	–78.50994	2.3
SP-07		Cape Fear	0210564590	Hammonds Creek at SR 1709 near Elizabethtown, NC	34.57002	–78.56049	12.0
SP-08		Cape Fear	0210687150	Big Swamp at SR 1441 near Clement, NC	35.08855	–78.59019	3.6
SP-09		Cape Fear	02107005	Cypress Creek at SR 1503 near Ammon, NC	34.78778	–78.50896	7.6
	SP-09A	Cape Fear	344734078312901	Drainage ditch to Cypress Creek near Ammon, NC	34.79279	–78.52442	6.9
SP-10		Cape Fear	02106011	Unnamed tributary to Bearskin Swamp at SR 1240 at Concord, NC	34.98793	–78.43314	1.5

Table 1. Study network, including primary and associated secondary sites, monitored for water quality in the North Carolina Coastal Plain.—Continued

[ID, identification; HUC, hydrologic unit code; USGS, U.S. Geological Survey; NC, North Carolina; HWY, highway; SR, secondary road; mi^2, square miles]

Primary study ID (see fig. 2)	Secondary study ID associated with primary sites (see appendix A1)	River basin	USGS station number	USGS station name	Decimal latitude	Decimal longitude	Drainage area (mi^2)
SP-11		Cape Fear	0210608620	Six Runs Creek at SR 1742 near Giddensville, NC	35.14064	−78.25847	5.6
	SP-11A	Cape Fear	0210608603	Six Runs Creek at SR 1736 near Hobbton, NC	35.16458	−78.27822	0.7
	SP-11B	Cape Fear	0210608607	Six Runs Creek near Hobbton, NC	35.15719	−78.26996	1.2
	SP-11C	Cape Fear	0210608610	Unnamed tributary to Six Runs Creek near Giddensville, NC	35.15619	−78.26846	0.2
	SP-11D	Cape Fear	0210608612	Six Runs Creek near Giddensville, NC	35.15041	−78.26580	2.3
SP-12		Cape Fear	0210778820	Bear Swamp at SR 1301 at Bowdens, NC	35.05736	−78.13150	3.3
SP-13		Cape Fear	0210782005	Nahunga Creek at SR 1301 near Warsaw, NC	35.02692	−78.01086	8.2
SP-14		Cape Fear	0210760950	Poley Branch at SR 1534 at Outlaws Bridge, NC	35.15245	−77.85116	4.6
SP-15		Cape Fear	0210760860	Buck Marsh Branch at SR 1753 near Hines Crossroads, NC	35.18423	−77.87220	4.5
SP-16		Cape Fear	0210798920	Stephens Swamp at SR 1807 at Quinns Store, NC	34.88644	−77.72953	2.8
SP-17		Cape Fear	0210858154	Tenmile Swamp at SR 1207 near Cypress Creek, NC	34.76237	−77.66882	6.0
SP-18		Cape Fear	0210850250	Doctors Creek at SR 1129 near Shanghai, NC	34.75101	−78.16391	6.6

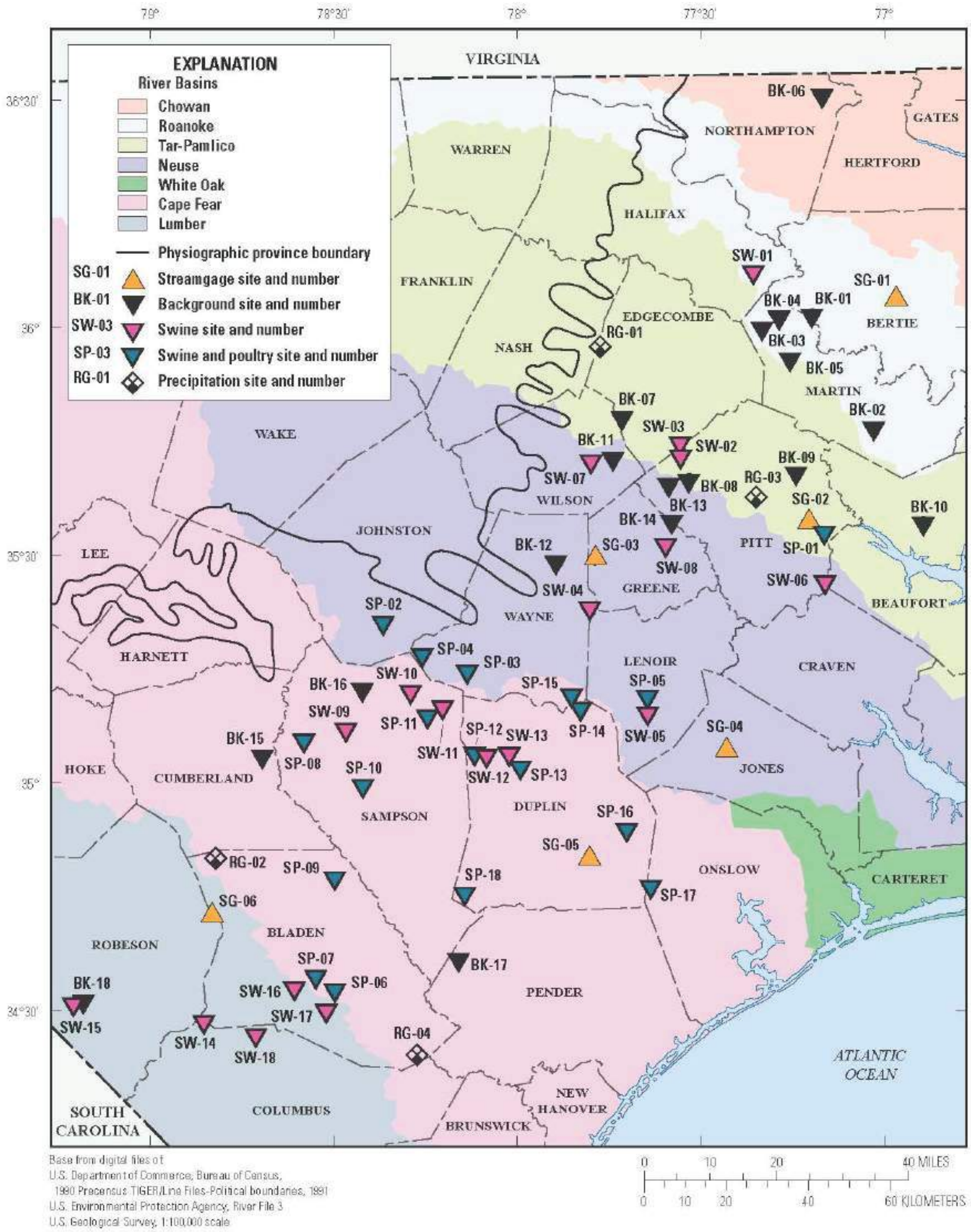


Figure 2. Locations of background, swine, and swine and poultry study sites, streamgage sites, and precipitation sites in the North Carolina Coastal Plain study area.

Land Cover and Hydrologic Soil Groups

Watershed attributes for land cover and hydrologic soil groups (HSGs) were compiled using StreamStats. Land-cover information was derived from the 2006 National Land Cover Database (NLCD) (Fry and others, 2011), which includes 15 individual land-cover classes. These 15 individual land-cover classes were aggregated into 8 principal land-cover categories (developed, forested, shrub, crops, grassland, wetlands, barren, and water), which were summarized for each watershed (appendix A2-1).

The study sites contain HSGs with varying degrees of soil drainage capacity. Data used to characterize the distribution of HSGs within the study sites were obtained through the U.S. Department of Agriculture Soil Survey Geographic Database (Soil Survey Staff, Natural Resources Conservation Service, n.d.). The areal extent and relative percentage for the four major HSGs (A, B, C, and D) and three dually classified HSGs (A/D, B/D, and C/D) were determined within the watershed of each site (appendix A2-2). Soils in HSGs A and B have low to moderately low runoff potential when thoroughly wet. Soils in HSGs C and D have moderately high to high runoff potential when thoroughly wet. Thus, soils in HSGs A and B have a higher degree of drainage, or water infiltration, as compared to soils in HSGs C and D, which are more poorly drained.

The dual hydrologic groups represent wet soils that were naturally classified as very poorly drained (HSG D) because of the presence of a water table within 2 ft of the land surface (U.S. Department of Agriculture, Natural Resources Conservation Service, 2009). If enhanced drainage measures, such as field ditches and subsurface tile drains, are used to maintain the seasonal high water table at least 2 ft below the surface, then the soils are characterized by the first letter of the dual groups (A/D, B/D, or C/D) on the basis of their saturated hydraulic conductivity and depth of the water table when drained (U.S. Department of Agriculture, Natural Resources Conservation Service, 2009). For this study, the data compiled for dual HSGs A/D, B/D, and C/D are assumed to represent drained soil conditions and were summed with their respective major HSGs to yield HSG total A, HSG total B, and HSG total C (appendix A2-2).

Wastewater Discharge Facilities and Non-Discharge Facilities

Information on NPDES-permitted wastewater-discharge facilities and permitted non-discharge facilities was provided by DWR (Michael Tutwiler, North Carolina Division of Water Resources, written commun., April 2012). Wastewater-discharge facilities that were considered included NPDES-permitted major municipal, minor municipal, major industrial/commercial, and 100 percent domestic discharge facilities. Harden and others (2013) previously indicated that point-source contributions of nutrients from wastewater-discharge facilities can have a significant influence on watershed nutrient yields in North Carolina. GIS analyses were used to map the locations of the discharge facilities in the Coastal Plain study area and to verify that none of the sites selected for study contained permitted dischargers.

GIS analyses also were performed to determine whether any permitted non-discharge facilities, which include wastewater irrigation, infiltration, or reclamation systems and land application of residual solids, were associated with the study sites. Only 2 of the 54 sites (SW-07 and SP-09) were found to have associated non-discharge facilities (appendix A3-1). Site SW-07 (appendix fig. A1-25) contains one residual solids land-application field, and site SP-09 (appendix fig. A1-45) contains two residual solids land-application fields. Any potential effects of these residual solids application fields on the water-quality results obtained at sites SW-07 and SP-09 are considered minimal and are not discussed in this report.

CAFOs

Available information on permitted CAFOs, including swine, cattle, and wet-poultry operations, was provided by DWR (Keith Larick, North Carolina Division of Water Resources, written commun., April 2012). All permitted CAFOs located in the 54 primary watersheds were mapped using GIS processes. The subgroups of the BK, SW, and SP study sites were operationally defined on the basis of the absence or presence of permitted active swine CAFOs located within the watersheds. None of the sites contained permitted cattle or wet-poultry CAFOs. Dry-litter poultry CAFOs, which are not required to have permits, were present in the SP watersheds.

Swine CAFO Attributes

Attribute data for the swine CAFOs were based on available information for facilities having either an active or inactive State of North Carolina permit. Swine CAFOs with active permits represent those facilities with ongoing swine production and field applications of swine-waste manure from the storage lagoons. Swine CAFOs with inactive permits represent former swine production facilities that are no longer operational. The inactive facilities currently have no swine animals or ongoing disposal of waste manure in application fields; however, remnant infrastructure, including barns and (or) inactive lagoons, may still be located at some of these facilities. The GIS analyses indicated that 10 of the study sites have 1 or 2 inactive-swine permits (appendix A3-2). Other than the permit numbers and locations, no other data were available for these inactive CAFOs. The active CAFOs, with ongoing waste-manure applications, are considered to have a more pronounced influence than the inactive CAFOs on water-quality conditions at the sites. Given the lack of information available for the inactive CAFOs, data evaluations conducted during the study focused on the permitted active swine CAFOs; the permitted inactive swine CAFOs were not considered further.

Several steps were taken in compiling attribute data for the active swine CAFOs. All active swine CAFOs within or along the boundaries of the 18 SW and 18 SP watershed sites were identified. Data provided by DWR for each active swine CAFO included information on the regulated swine activity, number of available acres for applying manure, amount of allowable plant available nitrogen (PAN), amount of generated PAN, and whether tile drains have been documented at the CAFO (appendix A3-3).

The regulated swine activity includes the type of swine production at the facility as well as the maximum annual average number of swine that can be produced. Seven types of swine production are associated with the CAFOs (Keith Larick, North Carolina Division of Water Resources, written commun., April 2012; table 2). Although multiple swine production activities are noted for some CAFOs, most produce only one type of swine. The average weight of swine produced and, consequently, the amount of waste manure generated by the swine population at a given CAFO depend on the type(s) of swine production at the facility. The maximum annual average number of swine (appendix A3-3) was multiplied by its respective average swine weight (table 2) to compute a total swine weight by production type. The number of swine and swine weights for all production types were summed to yield the total swine and total swine steady state live weight (SSLW) for each active CAFO.

The number of available acres listed for each active CAFO represents the total field acreage available at the facility for applying swine-waste manure (appendix A3-3). For a given facility, the amount of field acreage used for waste-manure applications during a given year may be lower than available. No information on the frequency and timing of applications or individual fields used was readily available for the CAFOs. The reported values for allowable PAN represent the maximum permitted amount of PAN that can be field applied annually at each CAFO. The reported values for generated PAN represent the calculated amount of PAN generated in waste manure that was field applied during 2012 at each CAFO (Keith Larick, North Carolina Division of Water Resources, written commun., July 2013). Ideally, the amount of generated PAN will be less than its allowable PAN on an annual basis such that the facility is not applying more PAN than allowed based on its permit.

Table 2. Swine production type and average swine weight associated with concentrated animal feeding operations in the study area.

Swine production type	Average weight of swine by production type (pounds)
Gilts	150
Wean to feeder	30
Wean to finish	115
Feeder to finish	135
Farrow to wean	433
Farrow to feeder	522
Farrow to finish	1,417

Qualitative information on the documented presence of tile drains at the CAFOs (appendix A3-3) was based on those either reported by the facility operator or identified by DWR facility inspectors; however, no specific information was available on the number or locations of documented tile drains at the facilities. Although there are no documented tile drains for some CAFOs, this may not be completely accurate because there are likely tile drains located at some facilities, the existence of which is unknown, and these would have gone unreported. The tile drain data are provided for informational purposes and are not considered to accurately reflect the extent to which subsurface tile drains may or may not be associated with the swine CAFO waste-manure application fields in the SW and SP study sites.

Available orthoimagery in Google Earth (http://www.google.com/earth/; accessed May 2012) was visually examined to identify the total number of lagoons and swine barns associated with each active swine CAFO and, of these, how many of the lagoons and barns were located within the watershed boundaries (appendix A3-3). Some of the CAFOs were located along the watershed drainage boundaries and, under these circumstances, overland runoff and groundwater flow from those facilities may be transported toward receiving streams both within and outside of the study watersheds. In these cases, the permit attribute data associated with CAFOs situated along the drainage boundaries were adjusted with a correction factor to allocate that fraction of the data deemed to be associated within the study sites (appendix A3-3). Where needed, the correction factor used to adjust the attribute data generally was taken as the ratio of swine barns located within the watershed to the total swine barns associated with the CAFO.

Attributes for the individual swine CAFOs, which reflect adjustments applied for total swine, total swine weight, available acres, PAN allowed, and PAN generated, are provided in appendix A3-4. This information was used to compute the total number of active swine CAFOs, lagoons, swine barns, swine animals and weight, available acres, allowable PAN, and generated PAN within each of the SW and SP watershed sites (appendix A3-5). Total watershed densities per square mile of swine barns, swine animals, swine weight (in tons), and available acres were determined as additional parameters for each site for use in evaluating the water-quality data.

Poultry CAFO Attributes

Available orthoimagery in Google Earth (http://www.google.com/earth/; accessed May 2012) was visually examined to identify apparent dry-litter poultry CAFOs and their associated number of poultry barns located within each watershed of the study sites. The SP sites were the only study sites determined to have one or more apparent dry-litter poultry CAFOs; these sites also contain one or more permitted active swine CAFOs. The apparent dry-litter poultry CAFOs were visually distinguished from the documented swine CAFOs on the basis of the presence of waste-storage lagoons at the permitted swine facilities and the absence of any waste-storage lagoons at the dry-litter poultry facilities. For verification purposes, a list of the apparent dry-litter poultry CAFOs identified for the 18 SP sites was provided to DWR for subsequent review by the North Carolina Department of Agriculture and Consumer Services, which indicated that the apparent dry-litter poultry CAFOs identified during this study were indeed active poultry facilities (Keith Larick, North Carolina Division of Water Resources, written commun., November 2012). No specific information on the operational characteristics (such as types and numbers of poultry raised, manure applications, or years of operation) for the dry-litter poultry CAFOs was publicly available for use in this study. Hereafter, the dry-litter poultry CAFOs at the study sites will be referred to as poultry CAFOs.

For this study, each cluster of poultry barns identified at the SP sites was considered to represent an individual poultry CAFO. Spatial coordinates and number of barns for the poultry CAFOs are provided in appendix A3-6. Each poultry CAFO was assigned a unique identifier, or field number, for use in this study. In some cases, adjacent poultry barn clusters may actually be part of the same operation. Similar to the process described previously for the swine CAFOs, in those cases where a poultry CAFO was located along the watershed drainage boundary, a prorated number of poultry barns was assigned to the CAFO to represent that fraction of the facility deemed to be within the watershed. The compiled information for the individual poultry CAFOs (appendix A3-6) was used to compute the total number of poultry CAFOs and poultry barns, as well as poultry barn density (barns per square mile), for each SP study site (appendix A3-7).

Data Collection

This section outlines procedures that were used to compile precipitation and streamflow monitoring data for examining hydrologic conditions in the study area. Sample collection procedures, laboratory analyses, and data quality-assurance practices are described for the water-quality data.

Precipitation and Streamflow

Precipitation data were obtained from four active USGS raingage monitoring stations (sites RG-01 through RG-04; table 3) in the Coastal Plain study area (fig. 2). Precipitation was measured at each site by using a tipping-bucket raingage that recorded precipitation at 15-minute intervals. Calibration checks were conducted semiannually on the raingages to ensure the accuracy of recorded data (U.S. Geological Survey, 2006). Precipitation data for sites RG-01, RG-02, RG-03, and RG-04 (table 3) are available from the USGS National Water Information System (NWIS) database (http://waterdata.usgs.gov/nc/nwis).

The precipitation data were used to better understand the extent to which each sampling date during the surface-water sampling periods was preceded by relatively wet or dry climatic conditions. For each raingage site, a cumulative total precipitation was computed for the 7-day period immediately preceding each date that samples were collected. Minimum, maximum, and mean values of the cumulative 7-day precipitation totals for the four raingage sites were determined for each sampling date for use in data analysis.

Ideally, instantaneous stream discharge would be measured to document streamflow conditions at the time water-quality samples are collected. However, the typical site conditions encountered during this study included low streamflow velocity coupled with varying degrees of submerged and floating aquatic vegetation within and along the stream channel. These conditions made it impractical to measure stream discharge during sample collections. Therefore, streamflow data were obtained from six active USGS streamgaging stations (sites SG-01 through SG-06; table 4) in the Coastal Plain study area (fig. 2) to describe regional hydrologic conditions during sampling periods. Streamflow data for the streamgage sites (table 4) are available from the USGS NWIS database (http://waterdata.usgs.gov/nc/nwis).

Table 3. Raingage monitoring sites in the North Carolina Coastal Plain study area used for collecting precipitation data.

[ID, identification; USGS, U.S. Geological Survey; NC, North Carolina]

Study site ID (see fig. 2)	USGS station number	USGS station name	Decimal latitude	Decimal longitude	Type of data collected
RG-01	355719077471345	Raingage at Tar River at NC 97 at Rocky Mount, NC	35.95536	−77.78683	Precipitation water quality
	02082585	Tar River at NC 97 at Rocky Mount, NC	35.95472	−77.78722	Continuous rainfall
RG-02	345006078493145	Raingage at Cape Fear River at Lock 3 near Tarheel, NC	34.83503	−78.82525	Precipitation water quality
	02105500	Cape Fear River at Wilm O Huske Lock near Tarheel, NC	34.83556	−78.82361	Continuous rainfall
RG-03	02084000	Tar River at Greenville, NC	35.61667	−77.37278	Continuous rainfall
RG-04	02105769	Cape Fear River at Lock 1 near Kelly, NC	34.40444	−78.29361	Continuous rainfall

Table 4. Streamgage monitoring sites in the North Carolina Coastal Plain study area used for compiling streamflow data.

[ID, identification; USGS, U.S. Geological Survey; NC, North Carolina; mi^2, square mile]

Study site ID (see fig. 2)	USGS station number	USGS station name	Decimal latitude	Decimal longitude	Drainage area (mi^2)
SG-01	0208111310	Cashie River at SR 1257 near Windsor, NC	36.04778	−76.98417	108
SG-02	02084160	Chicod Creek at SR 1760 near Simpson, NC	35.56167	−77.23083	45
SG-03	02091000	Nahunta Swamp near Shine, NC	35.48889	−77.80611	80.4
SG-04	02092500	Trent River near Trenton, NC	35.06417	−77.46139	168
SG-05	02108000	Northeast Cape Fear River near Chinquapin, NC	34.82889	−77.83222	599
SG-06	02134480	Big Swamp near Tarheel, NC	34.71028	−78.83639	229

Water-Quality Samples

Water-quality data compiled for the study include the analytical results for precipitation samples and surface-water samples. Precipitation samples were collected at raingage monitoring sites RG-01 and RG-02 from late July 2012 to early April 2013 for laboratory analyses. In this study, separate USGS station numbers are used for the precipitation water-quality data and the continuous rainfall data collected at monitoring stations RG-01 and RG-02 (table 3). The precipitation collectors were deployed for periods ranging from 2 days to 2 weeks to capture one or more rainfall events. The length of each deployment was based on the frequency and magnitude of rainfall events and the overall amount of rain that could be captured without overfilling the collection container. Clean sampling equipment was used for each deployment. Samplers were not deployed during periods of extreme cold to avoid freezing, which could compromise the analytical results.

Surface-water samples were collected at the 54 primary and 23 secondary study sites (table 1) for laboratory analyses. Samples at the primary sites were collected during six rounds of bimonthly sampling, during June, August, October, and December 2012, and February and April 2013. Samples were collected at the secondary sites once during the April 2013 sampling round. The number of days needed to collect samples during each round ranged from 3 to 6.

Water temperature, specific conductance, pH, DO, and barometric pressure were measured in the field during sample collections using instruments that were calibrated daily prior to sampling. Established, documented protocols were followed for collecting and processing samples for chemical analyses (U.S. Geological Survey, variously dated). Non-isokinetic methods were used for collecting samples because streamflow velocities generally were low. Samples were collected at the mid-depth of the water column at one or more points across the stream, depending on the stream width and type of road crossing (bridge or culverts). Subsamples collected from multiple points were composited into a single sample, representing the stream cross section.

Field equipment was cleaned between sampling sites (U.S. Geological Survey, variously dated). Samples were filtered and preserved in the field. A disposable 0.45-micron (µm) pore size capsule filter was used to process samples for major ions and filtered nutrient fractions. Samples collected for the determination of nitrogen-15/nitrogen-14 ($^{15}N/^{14}N$) and oxygen-18/oxygen-16 ($^{18}O/^{16}O$) isotopic ratios of nitrate plus (+) nitrite were filtered twice, first with a 0.45 µm capsule filter followed by a 0.20 µm disc filter, and subsequently frozen to prevent microbial degradation prior to laboratory analysis.

Nutrients and Major Ions

Surface-water samples were shipped to the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colorado, for chemical analysis of nutrients and major ions. Methods and reporting levels (RL) for each measured analyte (table 5) remained consistent for all samples analyzed during the study. Unfiltered samples were analyzed for concentrations of total ammonia+organic N and total P. Filtered samples were analyzed for concentrations of dissolved ammonia, dissolved nitrate+nitrite, and dissolved orthophosphate (ortho-P). Filtered samples also were analyzed to determine concentrations of dissolved calcium, chloride, magnesium, potassium, sodium, and sulfate.

The water-quality data for the surface-water samples are presented in appendix A4-1. One dataset includes water-quality results for all samples collected at the primary sites. The second dataset includes results for samples collected during the April 2013 sampling at the 9 primary sites and their 23 secondary sites. Analytical concentrations for the nitrogen species are reported in milligrams per liter as N and concentrations for ortho-P and total P are reported in milligrams per liter as P. The water-quality data also are available from the USGS NWIS database (http://waterdata.usgs.gov/nc/nwis).

Values for total organic N and total N (appendix A4-1) were computed from three directly measured nitrogen fractions (table 5). Total organic N was computed by subtracting dissolved ammonia from total ammonia+organic N. Total N was computed by summing total ammonia+organic N and dissolved nitrate+nitrite. If one of the underlying constituents used in computing total organic N or total N had a left-censored (<) value, then the < remark code was carried forward with the computed value. Although the < remark codes were carried forward with the total organic N and total N, they were ignored for the purpose of data evaluations in this study because the censoring levels associated with dissolved ammonia (RL = 0.010 mg/L) and dissolved nitrate+nitrite (0.04 mg/L) have minimal influence on the calculated values for total organic N and total N, respectively. Thus, examinations of the total organic N and total N data were based on the concentrations as reported in appendix A4-1 without regard to any < remark codes associated with the computed values. It is of note that, by default, total organic N and total N concentrations retrieved from the NWIS database retain the < remark code if one of the underlying constituents is left-censored. The handling of censored data is left to the discretion of data users.

Table 5. Nutrients and major ions measured in surface-water samples.

[N, nitrogen; P, phosphorus; mg/L, milligram per liter; EPA, U.S. Environmental Protection Agency; APHA, American Public Health Association]

Analyte	Reporting level, in mg/L	Analytical reference
Nutrients		
Ammonia as N, dissolved	0.010	Fishman (1993)
Ammonia + organic nitrogen as N, total	0.07	Patton and Truitt (2000)
Nitrate + nitrite as N, dissolved	0.04	Patton and Kryskalla (2011)
Orthophosphate as P, dissolved	0.004	Fishman (1993)
Phosphorus as P, total	0.004	USEPA (1993)
Major ions		
Calcium, dissolved	0.022	Fishman (1993)
Chloride, dissolved	0.06	Fishman and Friedman (1989)
Magnesium, dissolved	0.011	Fishman (1993)
Potassium, dissolved	0.03	APHA (1998)
Sodium, dissolved	0.06	Fishman (1993)
Sulfate, dissolved	0.09	Fishman and Friedman (1989)

Stable Isotopes

Surface-water and precipitation samples were shipped to the USGS Reston Stable Isotope Laboratory (RSIL) in Reston, Virginia, for analysis of stable isotopes by using a continuous flow isotope-ratio mass spectrometer. Surface-water samples were analyzed for stable isotope ratios of water (hydrogen-2/hydrogen-1 [$^{2}H/^{1}H$] and $^{18}O/^{16}O$) and (or) stable isotope ratios of dissolved nitrate+nitrite ($^{15}N/^{14}N$ and $^{18}O/^{16}O$). Precipitation samples were analyzed for stable isotope ratios of water ($^{2}H/^{1}H$ and $^{18}O/^{16}O$).

Stable isotope ratios are reported using the delta (δ) notation in units of parts per thousand (denoted as per mil or ‰) relative to a standard of known composition according to the following equation:

$$\delta\,(‰) = (R_{samp}/R_{stand} - 1) * 1{,}000 \quad (1)$$

where R_{samp} and R_{stand} are the ratios of the heavy to light isotope ($^{2}H/^{1}H$, $^{18}O/^{16}O$, or $^{15}N/^{14}N$) in the sample and standard, respectively.

Stable isotopes of water ($\delta^{2}H$ and $\delta^{18}O$) were analyzed in surface-water samples collected at the primary sites (appendix A4-1) and in precipitation samples collected at sites RG-01 and RG-02 (appendix A4-2) following methods outlined in Révész and Coplen (2008a, b). Results for $\delta^{2}H$ and $\delta^{18}O$ of water are reported with a 2-sigma (σ) uncertainty of ±2 ‰ and ±0.2 ‰, respectively. Analysis of stable isotopes of dissolved nitrate+nitrite ($\delta^{15}N$ and $\delta^{18}O$) in surface-water samples was based on the microbial denitrifier method (Sigman and others, 2001; Casciotti and others, 2002; Coplen and others, 2012). Measurements of $\delta^{15}N$ and $\delta^{18}O$ of dissolved nitrate+nitrite generally were performed on samples for the primary and secondary study sites with nitrate+nitrite concentrations greater than or equal to the RL of 0.04 mg/L (appendix A4-1). The $\delta^{15}N$ and $\delta^{18}O$ results are reported with 2-σ uncertainties of ±0.5 ‰ and ±1.0 ‰, respectively, when analyzed samples had nitrate+nitrite concentrations greater than or equal to 0.06 mg/L as N; the uncertainties are doubled for samples with nitrate+nitrite concentrations less than 0.06 mg/L as N.

An important issue to note regarding $\delta^{18}O$ analyses with the denitrifier method is that the $\delta^{18}O$ values generated for combined nitrate+nitrite may be underestimated if samples contain appreciable amounts of nitrite, yet the nitrite contributions to the $\delta^{18}O$ results are not taken into account (Casciotti and others, 2007). When available, measured concentrations of nitrite are used to make applicable corrections to the $\delta^{18}O$ results (Casciotti and McIlvin, 2007; Casciotti and others, 2007). In this study, however, samples were analyzed for combined nitrate+nitrite concentrations rather than individual concentrations of nitrate and nitrite. Therefore, the $\delta^{18}O$ values of nitrate+nitrite reported in appendix A4-1 may underestimate actual values. The extent to which the results may have been biased by unaccounted-for nitrite in the samples is unknown.

Although nitrite concentrations were not determined for samples collected during this study, nitrite typically constitutes a relatively small amount (<10 percent) of the overall nitrate+nitrite observed in streams in the North Carolina Coastal Plain. With nitrite likely representing less than 10 percent of the measured nitrate+nitrite in the study samples, the potential low bias associated with the $\delta^{18}O$ values determined for nitrate+nitrite should be relatively muted. The presence of unrecognized nitrite in samples with the lowest concentrations of nitrate+nitrite (near the analytical RL of 0.04 mg/L) would likely have the most pronounced bias on the nitrate+nitrite $\delta^{18}O$ results. Therefore, evaluations of the stable isotope data ($\delta^{15}N$ and $\delta^{18}O$) for dissolved nitrate+nitrite in this study were focused on those samples having nitrate+nitrite concentrations greater than or equal to 0.100 mg/L in an effort to reduce the potential uncertainties associated with the nitrate+nitrite $\delta^{18}O$ results.

Quality Assurance

Quality-control samples, including field blanks and replicate samples, were collected to document potential bias and variability in data that may result during the collection, processing, shipping, and handling of environmental samples (U.S. Geological Survey, variously dated). Field blanks were collected using inorganic-free water processed in the field with the same equipment used for the environmental samples. Field blanks help to identify contamination resulting from improperly cleaned equipment, field sampling activities and exposure, and laboratory practices. Overall, the results of the field blanks did not indicate any systematic or substantial quality-assurance issues with the environmental data. Replicate samples were collected to help document the variability in data results associated with sample collection, processing, and laboratory analysis. No quality-assurance problems were identified for the environmental dataset based on the replicate samples.

A total of 26 field blanks (appendix A4-3) and 26 replicate samples (appendix A4-4) were collected during surface-water sampling. One replicate sample was obtained during the collection of precipitation samples at site RG-02. Approximately 13 percent of the total number of samples collected during the study were quality-control samples. All surface-water blank and replicate samples were analyzed for nutrients and major ions. Stable isotopes of water ($\delta^{2}H$ and $\delta^{18}O$) were measured in replicate samples collected at the primary study sites and in the one precipitation replicate. Stable isotopes of nitrate+nitrite ($\delta^{15}N$ and $\delta^{18}O$) were measured in most surface-water replicate samples having detectable concentrations of nitrate+nitrite above the RL of 0.04 mg/L.

Most constituents were below analytical RLs in the field blanks (appendix A4-3). Magnesium, sodium, potassium, and sulfate were not detected in any blank samples. Concentrations of calcium and chloride in one blank sample (0.037 and 0.11 mg/L, respectively) were an order of magnitude lower than calcium and chloride concentrations measured in environmental samples (appendix A4-1). For nutrients, ortho-P was not detected in any blanks. Nitrate+nitrite was detected in one blank sample at a concentration (0.070 mg/L) just above the RL of 0.040 mg/L. Total phosphorus was also detected in one blank sample at a concentration (0.005 mg/L) just above the RL of 0.004 mg/L. Ammonia+organic N was detected in about 12 percent of the blank samples (3 of 26) at concentrations of 0.08 to 0.14 mg/L; however, there was no indication of systematic bias that would affect the environmental results. All ammonia+organic N concentrations measured for the environmental samples (appendix A4-1) exceeded the greatest concentration of 0.14 mg/L detected in the blank samples (appendix A4-3).

Ammonia was detected in about 27 percent of the blank samples (7 of 26) at concentrations of 0.011 to 0.020 mg/L. Blank samples frequently may become contaminated with ammonia when exposed to the atmosphere—both in the field and laboratory (Fishman, 1993). This is especially apparent when blanks are analyzed using low-level techniques, as was done in this study. Although some low-level contamination of ammonia may have occurred, any effects on the environmental data are considered minimal. Of the 344 total environmental samples, 319 had concentrations of ammonia above the analytical RL of 0.010 mg/L (appendix A4-1). Approximately 89 percent of these samples (283 of 319) had ammonia concentrations that exceeded the highest ammonia concentration of 0.020 mg/L detected in the blank samples (appendix A4-3). In addition, 75 percent of the samples (241 of 319) had ammonia concentrations greater than 0.040 mg/L, more than twice the highest concentration of 0.020 mg/L detected in the blanks.

Replicate samples were used to assess the overall precision of the entire sample collection, handling, and analysis approach. A statistical summary of the relative percent difference (RPD) determined for each analyte for all paired environmental and replicate samples is provided in table 6. The RPDs in analyte concentrations rarely exceeded 15 percent. Exceedances above 15 percent were limited to one or two replicate sample pairs for sulfate, nitrate+nitrite, total P, and $\delta^{18}O$ of nitrate+nitrite. The mean and median RPDs were less than about 5 percent for all the measured constituents (table 6), which indicates very good agreement between the environmental and replicate samples.

Prior to data analysis, the water-quality data (appendix A4-1) were reviewed to identify any obvious outliers or potential issues in the sample results. Site SW-02 was noted to have the highest measured values for specific conductance and the major ions, by up to an order of magnitude, among any of the study sites (appendix A4-1). Nutrient results for site SW-02 were similar to the other study sites. Site SW-02 contains both one small swine CAFO (1 barn with 4,330 swine) and a granite quarry in the headwater area of the watershed (appendix fig. A1-20). The very high ion concentrations for site SW-02 are suspected of being influenced by mining activities associated with the quarry; therefore, the results for specific conductance, calcium, magnesium, sodium, potassium, chloride, and sulfate for this site were excluded from data analyses in this report. Results for the August 26, 2012, sample collected at site BK-01 (appendix A4-1) were excluded from data evaluations because they were considered to be influenced by backwater conditions from the adjacent Roanoke River (appendix fig. A1-1) when storm runoff increased river levels by about 8 ft between August 25–26, 2012. In addition, the δ^2H and $\delta^{18}O$ isotopic results for sites BK-17 (appendix fig. A1-17) and SW-11 (appendix fig. A1-29), which were influenced by upstream impoundments, were considered atypical and also were excluded from the data evaluations.

Table 6. Statistical summary of relative percent differences in analyte concentrations for the environmental and replicate sample sets.

[RPD, relative percent difference; %, percent; N, nitrogen; P, phosphorus; δ, delta]

Analyte	Number of paired replicate samples[1]	Statistical measure			
		Minimum RPD (%)	Maximum RPD (%)	Mean RPD (%)	Median RPD (%)
Calcium, dissolved	26	0.0	5.6	1.4	1.0
Magnesium, dissolved	26	0.0	5.7	1.3	1.2
Sodium, dissolved	26	0.0	4.6	2.0	1.9
Potassium, dissolved	26	0.0	8.3	2.7	2.2
Chloride, dissolved	26	0.0	1.8	0.3	0.0
Sulfate, dissolved	26	0.0	16.6	1.2	0.4
Ammonia + organic nitrogen as N, total	26	0.0	10.7	2.6	1.4
Ammonia as N, dissolved	22	0.0	5.6	1.8	1.1
Nitrate + nitrite as N, dissolved	19	0.0	18.6	5.3	1.9
Orthophosphate as P, dissolved	21	0.0	14.0	2.8	1.4
Phosphorus as P, total	26	0.0	35.0	4.1	1.4
δ Hydrogen-2 of water, dissolved	25	0.0	6.2	2.7	2.6
δ Oxygen-18 of water, dissolved	25	0.0	2.4	0.8	0.7
δ Nitrogen-15 of nitrate + nitrite, dissolved	18	0.2	10.8	1.6	0.7
δ Oxygen-18 of nitrate + nitrite, dissolved	18	0.0	28.8	3.8	1.5

[1]Relative percent differences were computed when both samples in a pair had concentrations above analytical reporting levels.

Statistical Analyses

Statistical evaluations of the study data included the use of analysis of variance (ANOVA) tests and pair-wise multiple-comparison tests (Helsel and Hirsch, 1992). One-way ANOVA tests were used to test for significant differences in watershed attributes, such as basin drainage area, among the three watershed land-use types (BK, SW, and SP). Two-way, or multifactor, ANOVA tests were used to test for significant differences in surface-water constituents on the basis of sampling period and (or) land-use type. Because most of the study data are non-normally distributed, a non-parametric approach was used in which the ANOVA tests were performed on rank-transformed data to assess differences between groups. The use of statistical analyses that rely on data ranks, rather than actual data values, also is appropriate for examining water-quality data containing left-censored "<" values when the < values for a given constituent are censored to the same analytical RL (Bonn, 2008). Left-censored values reported for ammonia, nitrate+nitrite, and ortho-P in surface-water samples (appendix A4-1) were set equal to their respective RLs prior to ranking the data for use in statistical analyses.

Constituent concentrations were ranked for all samples collected from the 54 primary study sites during the 6 sampling periods. A two-way ANOVA test was then performed on the ranks of the concentration data to test for differences based on the grouping (or explanatory) variables of sampling period (June, August, October, and December in 2012, and February and April in 2013) and land-use type (including the 18 BK, 18 SW, and 18 SP sites). By evaluating sampling period and land-use type simultaneously, the effect of one explanatory variable can be measured while compensating for the other. The test compares the mean ranks of the constituent concentrations in the treatment groups to the overall mean rank for the entire dataset and determines whether there is an influential effect based on sampling period, land-use type, and (or) the combined interaction between sampling period and land-use type.

The ANOVA results for a given constituent may indicate that a statistically significant difference in the mean ranks of the concentrations exists among a particular treatment group (such as land-use type); however, it does not specify which of the group treatments (such as BK, SW, and SP site types) are different. Those constituents with significant differences identified by the ANOVA tests were analyzed further with Tukey pair-wise multiple-comparison tests to identify which sampling period comparison pairs and (or) land-use type comparison pairs had statistically different means in their ranked values. The ANOVA and pair-wise multiple-comparison analyses, which were tested at the 95 percent confidence level (P=0.05), were conducted using the S-Plus software suite (by TIBCO Software Inc.).

Relations of environmental variables among study sites identified as either being influenced or not influenced by CAFO waste manures were modeled using classification tree analyses (Breiman and others, 1984). Classification tree-based modeling is an exploratory technique for uncovering structure in the data. The classification tree models evaluate the response variable, or defined category (such as sites without CAFO effects and sites with CAFO effects), and the associated predictor variables (such as environmental attributes) to identify the predictor variables that best partition, or split, the response variable into increasingly homogeneous subsets. The resulting classification tree is simplified (pruned) by removing splits that do not contribute to a reduction in model error. The classification tree analyses were conducted using the S-Plus software suite (by TIBCO Software Inc.).

Characterization of Watershed Settings and Hydrologic Conditions

Information compiled on land cover, hydrologic soil groups (HSGs), and CAFO attributes was used to examine watershed settings among the study sites. Regional information on precipitation and streamflows and measurements of stable isotopes of water in collected samples were used to characterize general hydrologic conditions during the six water-quality sampling periods.

Watershed Settings

Land cover, HSGs, and CAFO attributes (appendixes A2-1, A2-2, A3-5 and A3-7) for the primary study sites were evaluated to identify similarities or differences in watershed settings among the BK, SW, and SP site groups. Land cover and HSGs were examined among all three site groups. Attributes for swine CAFOs were examined only for the SW and SP groups. A statistical summary of watershed attributes in each site group is provided in table 7.

The overall results of the statistical analyses indicate that the general watershed settings of the study sites are comparable among the BK, SW, and SP site groups. The primary difference between the land-use groups is that the BK sites contain no CAFOs, the SW sites contain swine CAFOs, and the SP sites contain both swine and poultry CAFOs. ANOVA tests indicated few statistical differences in land cover and HSGs among the BK, SW, and SP site groups (table 8). Shrub land cover, HSG total A, and HSG D were the only watershed attributes that were significantly different ($P<0.05$) between some site groups. In addition, the ANOVA tests also did not identify any statistically significant differences ($P<0.05$) in any of the swine CAFO attributes examined between the SW and SP site groups (table 8). In other words, the SW and SP groups are similar with respect to swine CAFO attributes in the watersheds but differ in that poultry CAFOs also are present only in the SP watersheds (table 7).

Table 7. Statistical summary of watershed attributes by land-use type.

[n, number; mi^2, square mile; %, percent; CAFO, concentrated animal feeding operation; PAN, plant available nitrogen; SSLW, steady state live weight; na, not applicable]

Watershed attribute (unit)	Background (BK) sites (n = 18)			Swine (SW) sites (n = 18)			Swine and poultry (SP) sites (n = 18)		
	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum
Land cover and hydrologic soil groups									
Drainage area (mi^2)	3.1	5.9	14.9	1.2	3.8	15.8	1.4	5.0	17.5
Developed (%)	0.6	4.6	10.0	1.2	4.3	9.1	1.0	4.0	6.4
Forested (%)	9.4	27.7	50.2	8.7	23.0	44.7	9.9	22.6	48.5
Shrubs (%)	2.7	6.8	17.0	4.1	10.5	23.5	6.4	11.5	16.8
Crops (%)	16.8	38.6	64.4	18.4	43.0	69.8	17.1	44.2	70.0
Grassland (%)	0.2	3.4	12.3	0.2	1.9	9.9	0.7	1.3	11.8
Wetlands (%)	4.3	15.6	55.0	6.3	13.3	27.3	3.7	12.8	21.2
Hydrologic soil group total A (%)	0.0	3.5	32.8	0.0	7.2	30.9	0.6	16.2	55.5
Hydrologic soil group total B (%)	12.6	58.0	88.3	27.9	52.6	87.6	13.8	54.0	86.0
Hydrologic soil group total C (%)	0.0	14.4	33.2	1.2	23.5	52.8	0.3	17.2	56.1
Hydrologic soil group D (%)	1.1	13.5	58.0	1.2	7.2	29.5	0.0	6.5	64.1
CAFO attributes									
Permitted active swine CAFOs (total)	na	na	na	1.0	1.5	12	1.0	3.0	10
Total allowable PAN (pounds)	na	na	na	2,347	38,760	132,355	2,743	36,239	253,906
Total generated PAN (pounds)	na	na	na	1,472	21,779	74,319	1,870	19,144	114,271
Swine lagoons (total)	na	na	na	1	3	18	1	5	15
Swine barns (total)	na	na	na	1	13	45	4	15	59
Swine animals (total)	na	na	na	1,200	9,225	65,532	550	9,928	67,797
Total swine SSLW (tons)	na	na	na	65.0	956	3,067	74.3	847	4,719
Available swine acres (total)	na	na	na	7.2	156	610	10.0	150	1,413
Swine barn density (barn/mi^2)	na	na	na	0.1	2.4	13.5	0.9	2.9	9.6
Swine animal density (animal/mi^2)	na	na	na	370	2,448	10,388	242	2,394	9,139
Swine weight density (ton/mi^2)	na	na	na	7.3	180	701	16.3	146	625
Swine acre density (acre/mi^2)	na	na	na	0.8	39	176	2.2	27	187
Active poultry CAFOs (total)	na	na	na	na	na	na	1.0	1.0	8
Poultry barns (total)	na	na	na	na	na	na	1.0	4.0	35
Poultry barn density (barn/mi^2)	na	na	na	na	na	na	0.2	0.9	5.7

Table 8. Summary results of the ANOVA and Tukey multiple-comparison tests of watershed attributes by land-use type.

[The null hypothesis was that the mean ranks of each distribution were the same. ANOVA, analysis of variance; *, indicates significant difference (P < 0.05); ns, no significant differences between site types based on ANOVA test; BK, background site type; SW, swine site type; SP, swine and poultry site type; CAFO, concentrated animal feeding operation; PAN, plant available nitrogen; SSLW, steady state live weight]

Watershed attribute	ANOVA test	Tukey multiple-comparison test
	p-value	Site-type comparison pairs significant at $\alpha = 0.05$
Land cover and hydrologic soil groups		
Drainage area	0.0901	ns
Developed	0.7661	ns
Forested	0.3564	ns
Shrub	0.0008*	BK-SW and BK-SP
Crops	0.2529	ns
Grassland	0.0920	ns
Wetlands	0.3126	ns
Hydrologic soil group total A	0.0005*	BK-SP and SW-SP
Hydrologic soil group total B	0.4401	ns
Hydrologic soil group total C	0.6864	ns
Hydrologic soil group D	0.0358*	BK-SP
Swine CAFO attributes		
Permitted active swine CAFOs	0.0768	ns
Total allowable PAN	0.7332	ns
Total generated PAN	0.5980	ns
Swine lagoons	0.2239	ns
Swine barns	0.2530	ns
Swine animals	0.3183	ns
Total swine SSLW	0.6870	ns
Available swine acres	0.8770	ns
Swine barn density	0.4008	ns
Swine animal density	0.9014	ns
Swine weight density	0.8043	ns
Swine acre density	0.6198	ns

Hydrologic Conditions During Sampling

Typical site conditions during sampling at most of the study sites included low streamflow velocity coupled with varying degrees of submerged and floating aquatic vegetation within and along the stream channel. Because of these conditions, it was not feasible to measure stream discharge at the study sites during sampling. Therefore, regional precipitation and streamflow data collected at active USGS monitoring stations (tables 3, 4; fig. 2), as well as δ^2H and $\delta^{18}O$ isotopic results for precipitation and stream samples, were used to assess general hydrologic conditions in the study area during the six sampling periods (June, August, October, and December in 2012, and February and April in 2013).

Precipitation

Regional precipitation measured during the study at the raingage monitoring sites (table 3; fig. 2) was slightly below normal levels. The annual precipitation recorded from May 1, 2012, through April 30, 2013, at raingage sites RG-01 (35.77 inches [in.]), RG-02 (40.49 in.), RG-03 (47.98 in.), and RG-04 (48.34 in.) has an average value of 43.14 in. Note that the annual values for RG-01 and RG-03 represent a lower limit because these sites had 17 days and 3 days, respectively, of missing data where precipitation was not recorded. The average annual precipitation is 45.60 in. if site RG-01 is excluded. Normal average annual precipitation in the study area, based on the 30-year period 1971–2000, ranges from about 46 to 52 in. (State Climate Office of North Carolina, n.d.).

Mean 7-day precipitation totals were used to document the differences in the amount of rainfall in the study area among the water-quality sampling periods (table 9; fig. 3). Overall, antecedent field conditions for the sampling periods were wetter for August and February, intermediate for June and April, and drier for October and December. It is important to note that for a given sampling event, there may have been considerable local differences in precipitation amounts among the study sites. For example, scattered thunderstorms occurred throughout the study area for the August period. The uneven distribution of precipitation is reflected by the higher standard deviations associated with the mean 7-day precipitation totals for August relative to the other sampling periods (table 9). The February sampling dates had mean 7-day precipitation totals similar to the August sampling dates, yet the lower standard deviations suggest that precipitation was more uniform across the study area during the February sampling event.

Table 9. Summary of the cumulative 7-day precipitation totals preceding each sample collection date based on raingage monitoring sites RG-01, RG-02, RG-03, and RG-04 (site locations in figure 2 and table 3).

Sample date	Number of primary study sites sampled	7-day precipitation total (inches)			
		Minimum	Maximum	Mean	Standard deviation
06/13/12	10	0.20	0.83	0.51	0.32
06/14/12	12	0.20	0.83	0.51	0.32
06/15/12	8	0.20	0.83	0.51	0.32
06/18/12	12	0.20	0.83	0.51	0.32
06/19/12	12	0.11	0.46	0.23	0.20
08/26/12	22	1.10	3.18	2.01	0.89
08/27/12	23	1.13	2.39	1.80	0.52
08/28/12	8	1.04	2.33	1.72	0.53
10/21/12	14	0.12	0.18	0.16	0.03
10/22/12	17	0.12	0.18	0.16	0.03
10/23/12	17	0.00	0.08	0.04	0.04
10/24/12	4	0.00	0.08	0.03	0.04
12/09/12	13	0.01	0.17	0.07	0.07
12/10/12	23	0.01	0.17	0.08	0.07
12/11/12	14	0.01	0.17	0.08	0.07
12/12/12	4	0.01	0.25	0.10	0.10
02/11/13	19	1.51	1.88	1.70	0.19
02/12/13	24	1.57	2.11	1.84	0.24
02/13/13	11	1.57	2.25	1.91	0.28
04/17/13	2	0.67	0.76	0.73	0.04
04/18/13	7	0.67	0.76	0.73	0.04
04/19/13	2	0.67	0.76	0.73	0.04
04/21/13	9	0.76	0.94	0.84	0.08
04/22/13	21	0.76	0.94	0.84	0.08
04/23/13	13	0.59	1.13	0.81	0.23

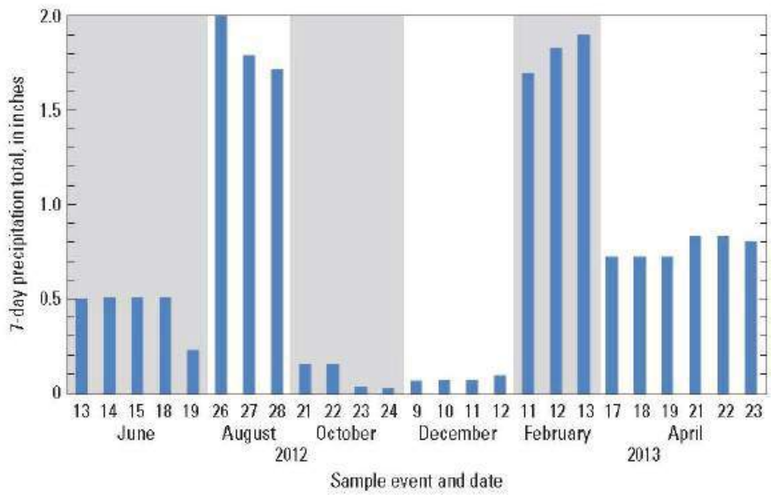


Figure 3. Mean cumulative 7-day precipitation totals preceding each sample collection date based on raingage monitoring sites RG-01, RG-02, RG-03, and RG-04 (site locations in figure 2 and table 3).

Streamflow

Relative differences in regional streamflow conditions during the water-quality sampling periods were inferred from streamflow records from six streamgage sites distributed throughout the study area (figs. 2, 4). The streamgage sites represent basin drainage areas ranging from 45 to 599 mi^2. Drainage areas for the primary study sites are considerably smaller, ranging from 1.2 to 17.5 mi^2. Although the magnitude of streamflow and the duration and timing of peak streamflows likely differ between the streamgage sites and the study sites, the hydrographs are useful indicators of relative streamflow trends throughout the study area during the sampling periods and the entire study period.

Streamflow conditions during most of the sampling periods were similar to or higher than historical streamflow conditions in the study area. Daily mean streamflows at the six streamgage sites during the study period (May 2012 through April 2013) are shown relative to long-term median daily mean streamflows for the 25-year period from May 1988 through April 2013 (fig. 4). In general, streamflows for the June, October, and April sampling periods were fairly similar to the long-term median values. Streamflows for the August and February periods tended to be substantially higher, and streamflows for the December period tended to be substantially lower relative to historical conditions.

Streamflow conditions varied among the six sampling periods (fig. 4). Compared to other sampling periods, streamflow conditions were relatively higher during the August and February sampling periods when precipitation amounts in the study area were higher (fig. 3) and overland transport of water to the streams was greater. The intermediate to lower streamflow conditions for the June, October, December, and April sampling periods reflect less precipitation and overland transport of water to the streams and a larger component of streamflow derived from groundwater compared to the August and February periods. The typically higher and more sustained stream-baseflow conditions (fig. 4) observed during the winter and early spring months (generally January to April) reflect greater groundwater discharge and likely higher inputs from field drainage ditches when the water table in the surficial aquifers is high. Variations in stream water quality at the study sites among sampling periods with higher versus lower relative streamflows may reflect relative differences in source contributions of water-quality constituents delivered through groundwater discharge and overland runoff.

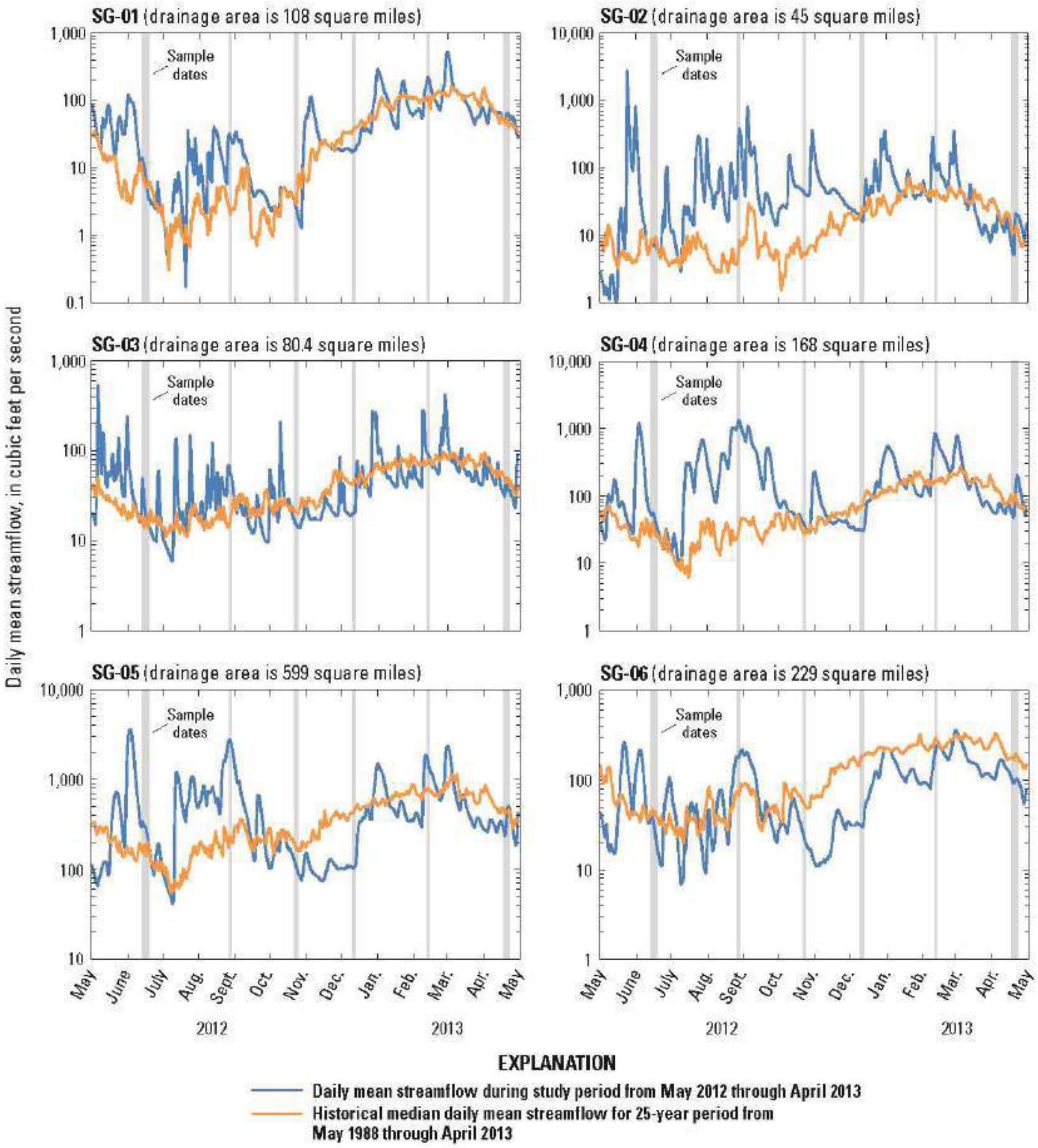


Figure 4. Streamflow hydrographs at sites SG-01, SG-02, SG-03, SG-04, SG-05, and SG-06 showing dates water-quality samples were collected during the study and historical median daily mean streamflows (site locations in figure 2 and table 4).

Water Stable Isotopes

Stable isotopes of water (δ^2H and $\delta^{18}O$) in precipitation and stream samples also were used to characterize general hydrologic conditions during the sampling periods. The δ^2H and $\delta^{18}O$ data for precipitation samples collected from July 2012 to April 2013 at rainfall monitoring sites RG-01 and RG-02 (fig. 2; appendix A4-2) were used to create a local meteoric water line (LMWL) for the Coastal Plain study area (fig. 5). The LMWL is represented by the linear relation between the δ^2H and $\delta^{18}O$ isotopic compositions in the precipitation samples:

$$\delta^2H = 8.33 * \delta^{18}O + 16.75 \qquad (2)$$

The slope of 8.33 for the LMWL determined in this study is similar to the meteoric water line (MWL) equation ($\delta^2H = 8.29 * \delta^{18}O + 10.94$) determined by Kendall and Coplen (2001) using average values of surface-water samples obtained from 391 sites throughout the United States and Puerto Rico.

The δ^2H and $\delta^{18}O$ isotopic compositions of the samples collected at the primary sites (appendix A4-1) were compared to the LMWL to examine general differences in stream hydrologic conditions during the sampling periods (fig. 6). In general, surface-water samples with δ^2H and $\delta^{18}O$ values that correspond to the LMWL indicate that water in the streams reflects more recent inputs of precipitation to the land surface, which ultimately reaches the streams through runoff and groundwater discharge, that has undergone little fractionation. Samples with δ^2H and $\delta^{18}O$ values that plot along a line with a slope lower than the LMWL can be an indication that post-rainfall processes, commonly evaporation, altered the isotopic composition of the stream water prior to sample collection (Kendall and Coplen, 2001). As surface water evaporates, there is a preferential release of the lighter ^1H and ^{16}O isotopes to the atmosphere, which increases the δ^2H and $\delta^{18}O$ values of the remaining stream water; the values become increasingly more positive as evaporation proceeds.

During the six sampling periods, the δ^2H and $\delta^{18}O$ values for the February 2013 stream samples corresponded most closely to the LMWL (fig. 6*E*), reflecting the recent inputs of overland runoff when evaporation was least likely to have occurred (figs. 3, 4). The regression line for the February 2013 samples, with a slope of 6.97, almost paralleled the LMWL. For reference purposes, the regression line for the February 2013 data was superimposed on each of the δ^2H and $\delta^{18}O$ isotopic plots for the other five periods (fig. 6) to relate the isotopic compositions for those periods to the February period. The δ^2H and $\delta^{18}O$ values for the August 2012 samples plotted along a line with a slope of 6.08 (fig. 6*B*) that was just below the slope of 6.97 for the February 2013 period. The August samples had the largest observed range in δ^2H values (–12.3 to –37.3 ‰) and $\delta^{18}O$ values (–2.3 to –6.5 ‰). The August samples in the lower part of the regression line had isotopic signatures similar to the LMWL, indicating that stream water at some of the sites had received recent inputs of overland runoff and was minimally influenced by evaporation. August samples in the upper part of the regression line had more positive isotope δ^2H and $\delta^{18}O$ values that diverged to the right of the LMWL (fig. 6*B*), reflecting increased effects of evaporation and a lack of recent runoff at some of the sites sampled during August.

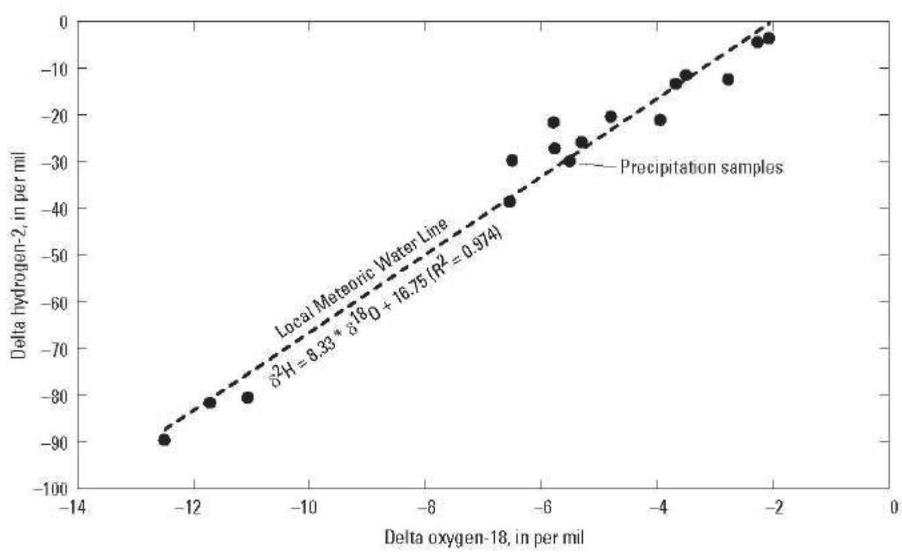


Figure 5. Comparison of delta oxygen-18 to delta hydrogen-2 isotope values in precipitation samples collected from July 2012 to April 2013 at raingage sites RG-01 and RG-02 in the Coastal Plain study area.

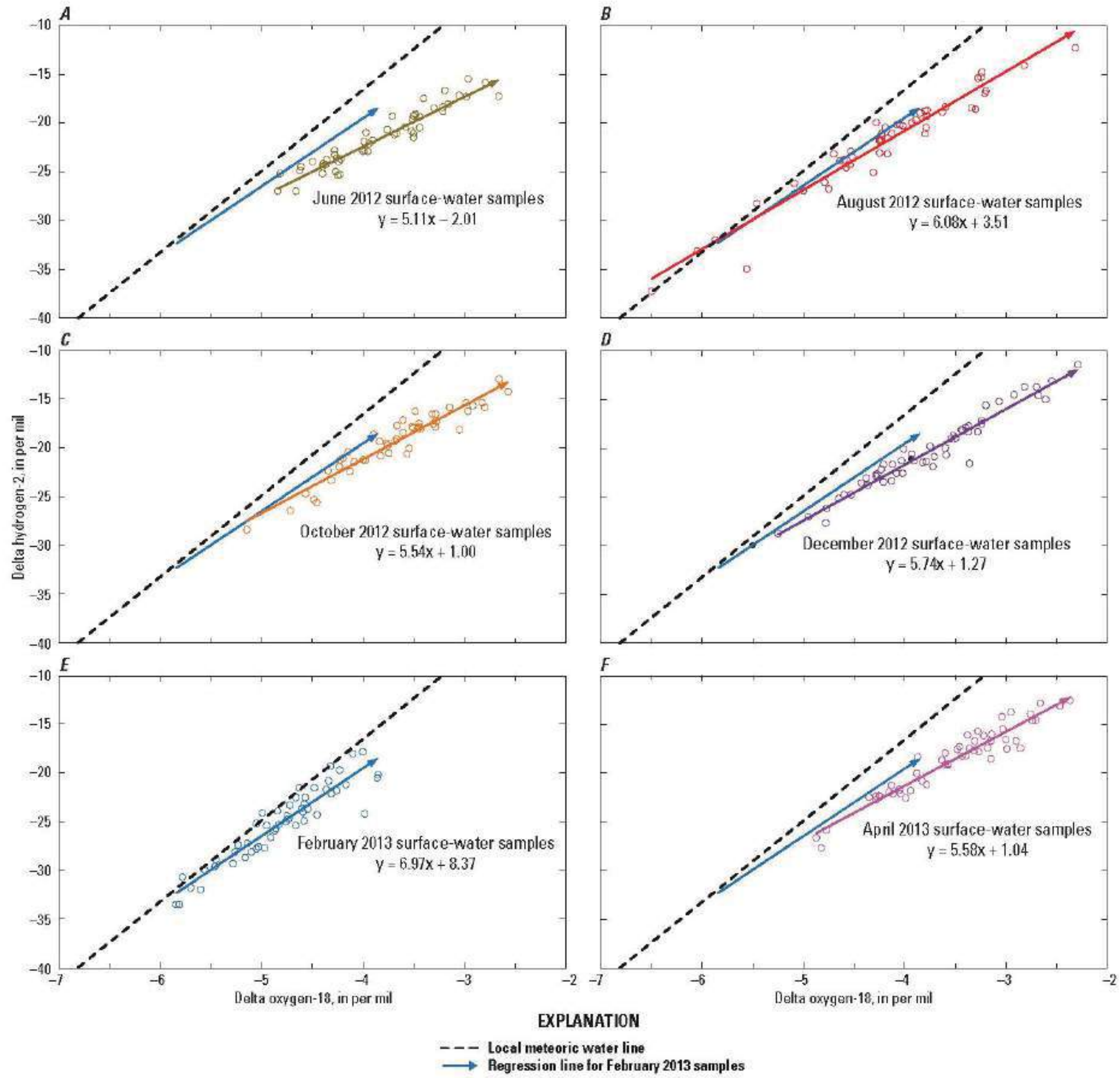


Figure 6. Comparisons of delta oxygen-18 to delta hydrogen-2 isotope values of surface-water samples for the (*A*) June 2012, (*B*) August 2012, (*C*) October 2012, (*D*) December 2012, (*E*) February 2013, and (*F*) April 2013 sampling periods relative to the local meteoric water line.

More pronounced effects of evaporation on the isotopic compositions at the stream sites were noted for the June, October, and December 2012 periods and the April 2013 period where the δ^2H and $\delta^{18}O$ values, with regression line slopes ranging from 5.11 to 5.74, plotted farthest away from the LMWL (fig. 6). These results support the previous discussion of the precipitation and streamflow data, which implied that streamflow conditions were relatively higher during the August and February periods as a result of increased rainfall and overland runoff (figs. 3, 4). Evaporation appeared to have a more influential effect on the surface-water δ^2H and $\delta^{18}O$ compositions during the June, October, December, and April periods. These periods were characterized by intermediate to lower streamflow conditions when there was less rainfall runoff to the streams and proportionally more input from discharging groundwater.

Comparison of Water-Quality Data by Sampling Period and Land-Use Type

Two-way ANOVA and multiple-comparison statistical tests were performed to characterize differences in stream water quality among the sampling periods (June, August, October, and December in 2012, and February and April in 2013) and watershed land-use types (BK, SW, and SP). Many of the water-quality properties and constituents were significantly influenced (ANOVA $P<0.05$) by one or both of the explanatory variables (sampling period and (or) land-use type) but there were no effects due to their combined interaction (sampling period:land-use type) (table 10). The lack of interaction indicates that the effects of sampling period and land-use type for a given constituent are independent; in other words, the effect of sampling period is the same across all land-use types and the effect of land-use type is the same across all sampling periods.

Seasonal and Flow-Related Water-Quality Differences

All of the water-quality properties and constituents, except calcium and the nitrate+nitrite isotopes ($\delta^{15}N$ and $\delta^{18}O$), had significant (ANOVA, $P<0.05$) differences among the sampling periods (table 10) based on data collected at the 54 primary sites. Differences reflected seasonal and hydrologic variations, as well as instream processes. Statistical summaries, by sampling period, of the original (non-ranked transformed) water-quality data are provided in tabular (table 11) and graphical formats (fig. 7) to aid the discussion. Figure 7 contains box plots for properties and constituents with significant differences (ANOVA $P<0.05$) among sampling periods; results of the multiple-comparison tests among the periods are denoted along the top of the plots. Rather than scrutinizing individual comparison pairs, the following discussion focuses on patterns among the sampling periods that reflect seasonal and hydrologic influences on water quality. Although ANOVA indicated a significant ($P=0.039$) difference for magnesium among sampling period (table 10), the multiple-comparison test did not identify any comparison pairs that were considered ($P<0.05$) different.

Water temperature followed an expected seasonal progression (fig. 7*A*). Specific conductance values were relatively lower during the August and February periods when rainfall was greatest, and higher for the October and December periods, when rainfall was least, although the difference was significant only for the December period (fig. 7*B*). Specific conductance in streams commonly is lower during high streamflows through dilution from overland runoff, and higher during low streamflows when baseflow, or groundwater discharge, is a larger component of the overall streamflow. Sodium (fig. 7*E*), potassium (fig. 7*F*), and chloride concentrations (fig. 7*G*) had distributions similar to specific conductance (fig. 7*B*) with highest concentrations during the drier December period.

In well-mixed, open flowing streams, DO concentrations typically are higher at cold temperatures and lower at warm temperatures. This is a result of higher solubility of dissolved gases in water at low temperatures. Although water temperatures (fig. 7*A*) followed expected seasonal patterns among the six sampling periods, there was no apparent relation between water temperature and DO (fig. 7*C*), with the exception of the February period. The streams examined in this study typically are slow moving and enriched with organic matter; low levels of DO are common in these stream settings. The variations in DO concentrations observed among the sampling periods likely reflect the integrated effects of hydrologic differences, such as the influx of oxygenated water from precipitation and overland runoff, and seasonal differences in the consumption of DO by microbial degradation of organic matter. The higher flow conditions for the February and August periods and intermediate flow conditions for the April period indicate more recent stream influxes of precipitation and runoff and, hence oxygenated water, were associated with these periods relative to the June, October, and December periods. The twofold difference in median DO concentrations between the February (8.0 mg/L) and August (3.6 mg/L) periods with the highest flow conditions appears to reflect seasonal differences in the microbial consumption of oxygen for degrading organic matter, which proceeds more quickly under warmer conditions and more slowly under cooler conditions. Although water temperatures were lower for October and December relative to August, the similarly low median DO concentrations for the drier October (2.4 mg/L) and December (2.1 mg/L) periods suggest that a substantial amount of microbial oxygen consumption occurred during the more sluggish streamflow conditions.

Concentrations of nutrients also differed among the sampling periods (table 10; fig. 7). Many biological, chemical, and physical processes can influence the forms and instream concentrations of the N and P constituents,

Table 10. Summary results of the two-way ANOVA tests on the ranked values of the water-quality properties and constituents based on sampling period and land-use type.

[The null hypothesis was that the mean ranks of each distribution were the same. *, indicates significant difference (P < 0.05); <, less than; N, nitrogen; P, phosphorus; δ, delta]

Explanatory grouping variable	p-values for water-quality properties				p-values for major ions					
	Water temperature	Specific conductance	Dissolved oxygen	pH	Calcium	Magnesium	Sodium	Potassium	Chloride	Sulfate
Sampling period	<0.001*	0.001*	<0.001*	0.015*	0.220	0.039*	<0.001*	<0.001*	<0.001*	<0.001*
Land-use type	0.254	<0.001*	0.157	<0.001*	0.084	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
Sampling period:Land-use type	0.224	0.936	0.751	0.977	0.996	0.980	0.921	0.800	0.367	0.778

Explanatory grouping variable	p-values for nutrients							p-values for isotopes	
	Ammonia + organic N	Ammonia	Total organic N	Nitrate + nitrite	Total N	Orthophosphate	Total P	δ Nitrogen-15 of nitrate + nitrite	δ Oxygen-18 of nitrate + nitrite
Sampling period	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	0.625	0.484
Land-use type	0.007*	<0.001*	0.166	<0.001*	<0.001*	0.533	0.106	<0.001*	0.221
Sampling period:Land-use type	0.322	0.405	0.335	0.906	0.457	0.755	0.726	0.954	0.721

Table 11. Statistical summary of water-quality properties and constituents by sampling period.

[diss., dissolved; mg/L, milligrams per liter; <, less than; µS/cm, microsiemens per centimeter; °C, degrees Celsius, N, nitrogen; P, phosphorus; O, oxygen; ‰, per mil]

Chemical constituent or property (unit)	June 2012				August 2012				October 2012			
	Number of samples	Minimum	Median	Maximum	Number of samples	Minimum	Median	Maximum	Number of samples	Minimum	Median	Maximum
Water-quality properties												
Temperature, water (°C)	54	18.5	21.3	26.2	52	20.6	23.1	27.3	52	12.1	13.9	17.8
Specific conductance (µS/cm at 25 °C)	53	48	121	318	51	49	107	318	51	51	133	440
Oxygen, diss. (mg/L)	54	0.03	1.9	8.1	52	0.04	3.6	6.9	52	0.02	2.4	9.2
pH (standard units)	53	4.9	6.1	7.0	52	4.7	6.1	7.2	52	5.1	6.2	7.0
Major ions												
Calcium, diss. (mg/L)	53	2.01	8.41	43.9	51	1.94	6.29	27.2	51	1.94	7.63	35.6
Magnesium, diss. (mg/L)	53	0.78	3.38	7.85	51	0.76	2.52	6.85	51	0.80	3.42	7.81
Sodium, diss. (mg/L)	53	3.74	5.99	15.1	51	2.17	5.24	16.2	51	3.04	6.79	36.0
Potassium, diss. (mg/L)	53	0.90	4.73	17.4	51	1.49	5.27	24.2	51	2.18	5.72	46.2
Chloride, diss. (mg/L)	53	7.60	15.0	34.8	51	5.06	12.7	35.1	51	7.05	17.6	65.3
Sulfate, diss. (mg/L)	53	0.19	3.91	33.5	51	0.14	5.36	29.3	51	0.14	4.34	43.0
Nutrients												
Ammonia + organic N, total (mg/L as N)	54	0.16	1.0	2.9	52	0.60	1.0	6.3	52	0.22	0.83	7.4
Ammonia, diss. (mg/L as N)	54	0.013	0.140	0.932	52	<0.010	0.060	4.05	52	<0.010	0.044	4.70
Total organic N (mg/L as N)	54	0.12	0.88	2.7	52	0.59	0.96	2.3	52	0.21	0.75	2.7
Nitrate + nitrite, diss. (mg/L as N)	54	<0.040	0.066	5.97	52	<0.040	0.123	4.28	52	<0.040	0.049	6.66
Total N (mg/L as N)	54	0.20	1.3	6.8	52	0.71	1.2	7.4	52	0.34	1.0	14.0
Orthophosphate, diss. (mg/L as P)	54	<0.004	0.039	0.461	52	<0.004	0.042	0.399	52	<0.004	0.029	0.466
Total P (mg/L as P)	54	0.020	0.140	0.981	52	0.013	0.141	0.702	52	0.012	0.101	0.860
Isotopes												
$\delta^{15}N$ of nitrate + nitrite (‰)	24	5.34	13.33	39.21	27	5.12	12.98	48.88	22	6.24	15.42	39.48
$\delta^{18}O$ of nitrate + nitrite (‰)	24	–1.39	7.86	19.89	27	0.67	9.46	22.98	22	2.37	8.66	19.63

Table 11. Statistical summary of water-quality properties and constituents by sampling period.—Continued

[diss., dissolved; mg/L, milligrams per liter; <, less than; µS/cm, microsiemens per centimeter; °C, degrees Celsius, N, nitrogen; P, phosphorus; O, oxygen; ‰, per mil]

Chemical constituent or property (unit)	December 2012				February 2013				April 2013			
	Number of samples	Minimum	Median	Maximum	Number of samples	Minimum	Median	Maximum	Number of samples	Minimum	Median	Maximum
Water-quality properties												
Temperature, water (°C)	54	8.9	12.7	17.1	54	7.2	11.1	14.8	54	11.6	14.3	21.1
Specific conductance (µS/cm at 25 °C)	53	49	141	465	53	56	114	328	53	52	120	271
Oxygen, diss. (mg/L)	54	0.01	2.1	7.4	54	1.9	8.0	10.5	54	0.02	5.0	10.1
pH (standard units)	54	5.1	6.0	7.0	54	4.2	6.0	6.7	54	4.7	6.3	7.0
Major ions												
Calcium, diss. (mg/L)	53	1.92	8.58	37.8	53	2.01	6.37	18.2	53	1.73	6.99	21.4
Magnesium, diss. (mg/L)	53	0.80	3.56	11.3	53	1.00	2.94	7.74	53	0.81	2.90	6.22
Sodium, diss. (mg/L)	53	3.26	7.33	24.2	53	3.73	5.89	16.7	53	3.78	6.75	17.4
Potassium, diss. (mg/L)	53	1.58	6.44	27.2	53	1.54	4.94	24.9	53	0.60	4.75	19.4
Chloride, diss. (mg/L)	53	7.62	20.0	59.1	53	7.89	14.7	37.5	53	8.84	15.4	34.4
Sulfate, diss. (mg/L)	53	0.21	3.53	46.7	53	2.43	10.8	28.6	53	0.31	4.37	15.7
Nutrients												
Ammonia + organic N, total (mg/L as N)	54	0.18	0.81	2.0	54	0.32	0.66	1.5	54	0.52	1.1	4.8
Ammonia, diss. (mg/L as N)	54	<0.010	0.056	0.761	54	<0.010	0.030	0.284	54	<0.010	0.182	3.42
Total organic N (mg/L as N)	54	0.18	0.70	1.4	54	0.30	0.56	1.4	54	0.48	0.85	2.0
Nitrate + nitrite, diss. (mg/L as N)	54	<0.040	<0.040	7.94	54	<0.040	0.993	15.9	54	<0.040	0.153	5.04
Total N (mg/L as N)	54	0.22	0.94	9.1	54	0.36	1.6	17.0	54	0.56	1.3	6.4
Orthophosphate, diss. (mg/L as P)	54	<0.004	0.034	0.713	54	<0.004	0.009	0.052	54	<0.004	0.034	0.347
Total P (mg/L as P)	54	0.011	0.128	1.14	54	0.009	0.044	0.525	54	0.013	0.132	0.859
Isotopes												
$\delta^{15}N$ of nitrate + nitrite (‰)	19	6.09	15.33	38.64	46	6.08	11.33	22.87	32	4.92	13.22	30.65
$\delta^{18}O$ of nitrate + nitrite (‰)	19	5.36	8.60	21.33	46	5.18	9.31	14.01	32	3.46	8.87	16.60

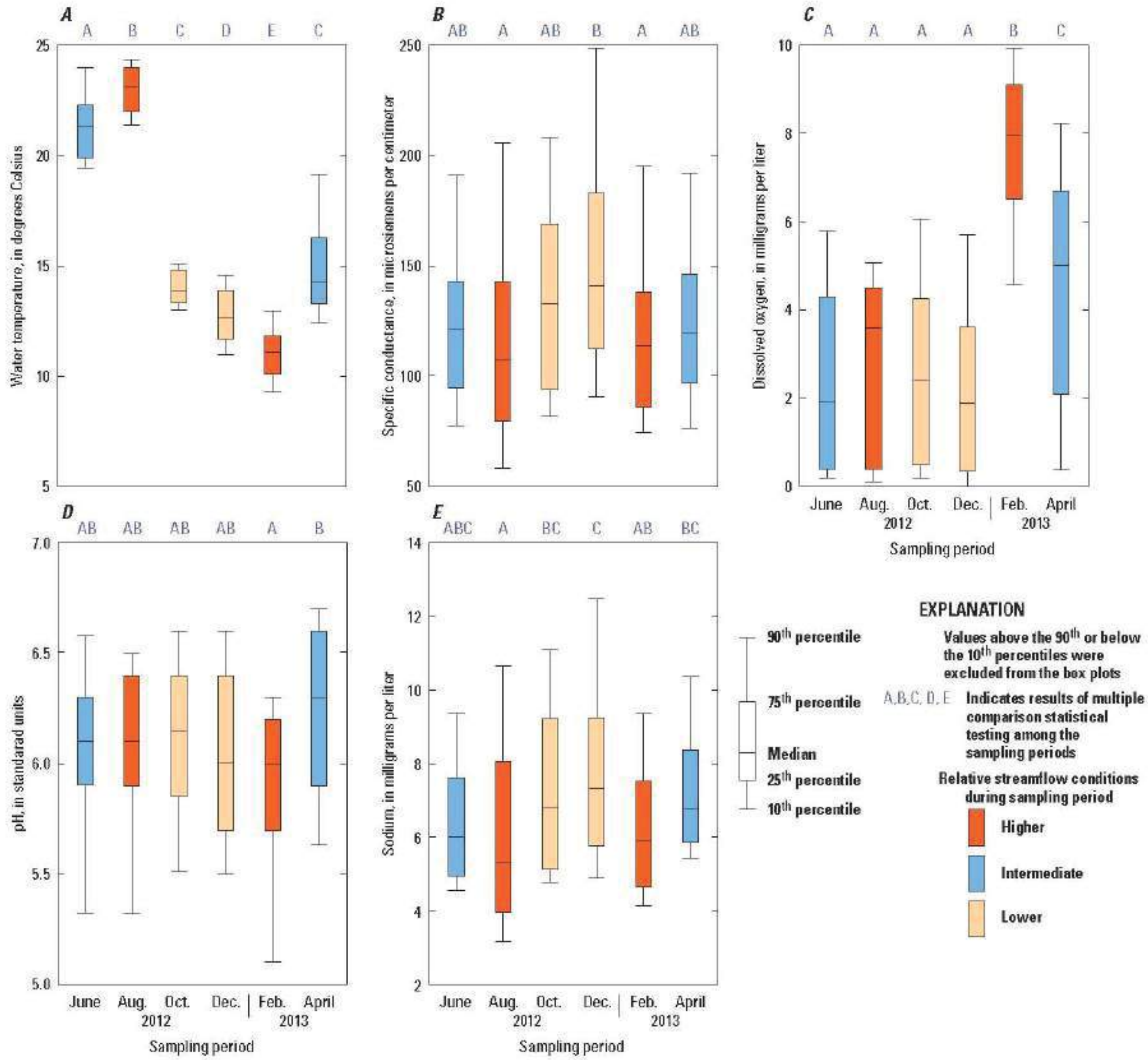


Figure 7. Distributions of (*A*) temperature, (*B*) specific conductance, (*C*) dissolved oxygen, (*D*) pH, (*E*) sodium, (*F*) potassium, (*G*) chloride, (*H*) sulfate, (*I*) ammonia plus organic nitrogen, (*J*) ammonia, (*K*) total organic nitrogen, (*L*) nitrate plus nitrite, (*M*) total nitrogen, (*N*) orthophosphate, and (*O*) total phosphorus for all study sites based on sampling period (for a given constituent, if a sampling period contains the same letter above it as another sampling period, there is no statistical difference between them at the 95 percent confidence level).

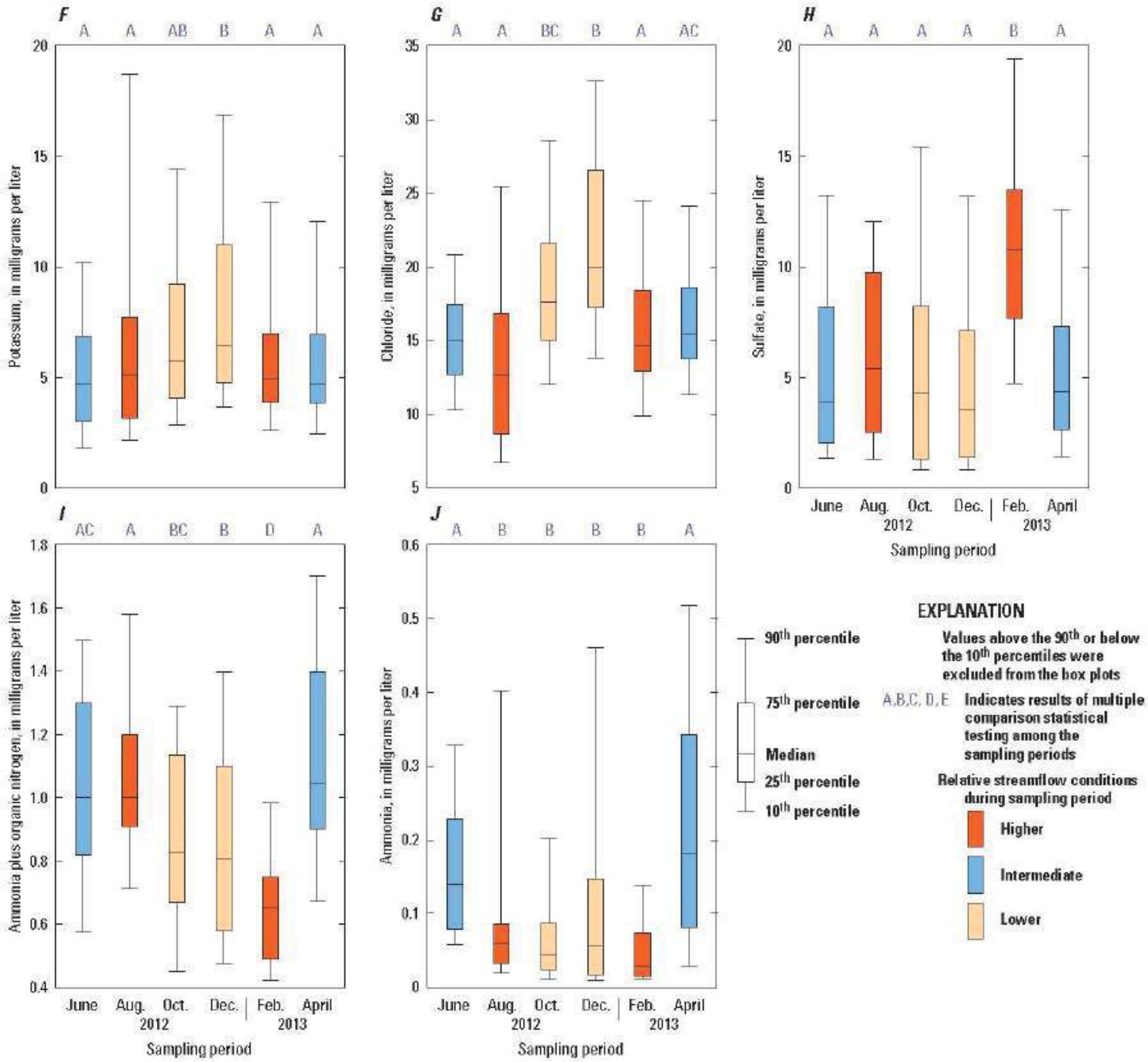


Figure 7. Distributions of (*A*) temperature, (*B*) specific conductance, (*C*) dissolved oxygen, (*D*) pH, (*E*) sodium, (*F*) potassium, (*G*) chloride, (*H*) sulfate, (*I*) ammonia plus organic nitrogen, (*J*) ammonia, (*K*) total organic nitrogen, (*L*) nitrate plus nitrite, (*M*) total nitrogen, (*N*) orthophosphate, and (*O*) total phosphorus for all study sites based on sampling period (for a given constituent, if a sampling period contains the same letter above it as another sampling period, there is no statistical difference between them at the 95 percent confidence level).—Continued

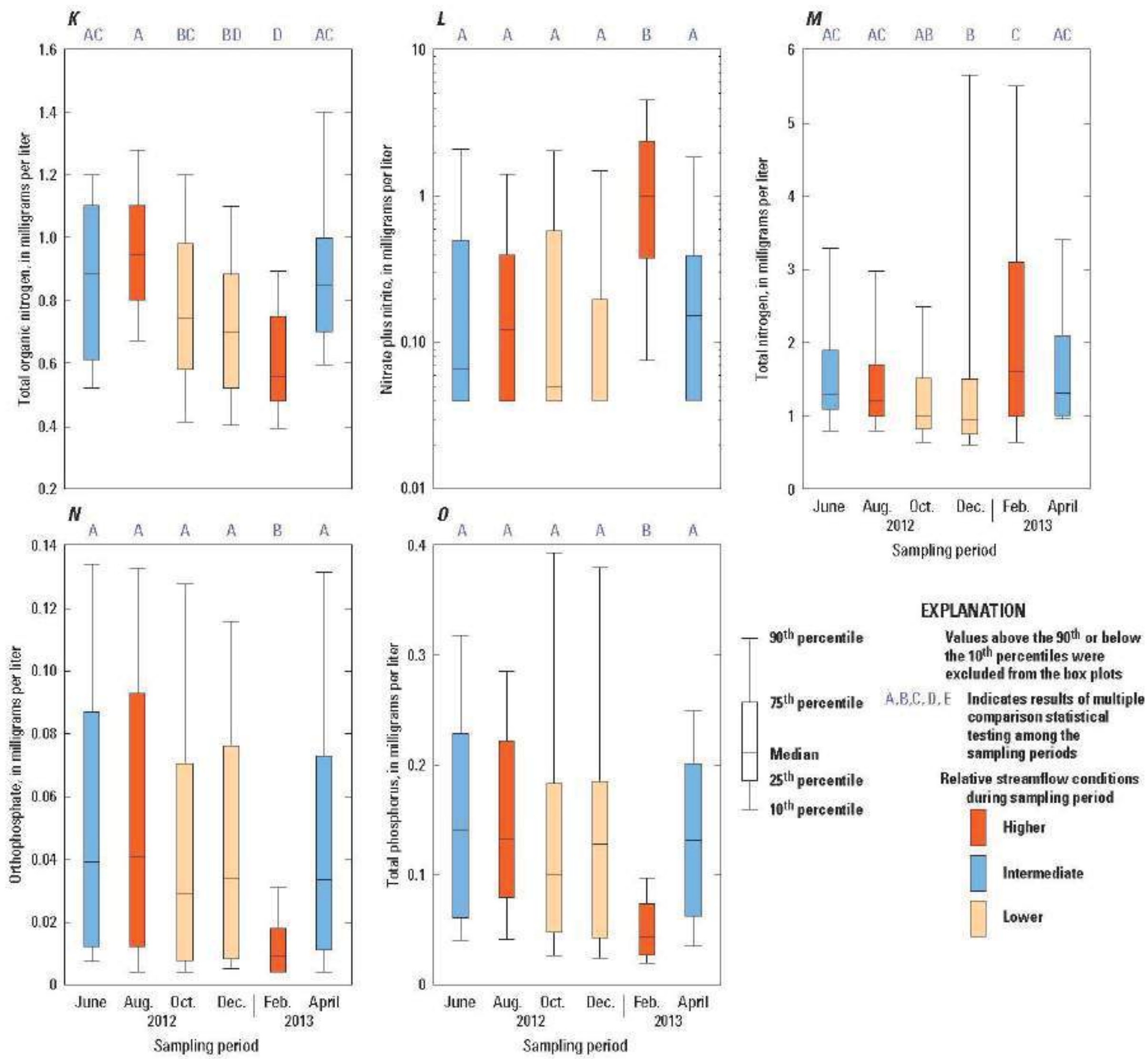


Figure 7. Distributions of (*A*) temperature, (*B*) specific conductance, (*C*) dissolved oxygen, (*D*) pH, (*E*) sodium, (*F*) potassium, (*G*) chloride, (*H*) sulfate, (*I*) ammonia plus organic nitrogen, (*J*) ammonia, (*K*) total organic nitrogen, (*L*) nitrate plus nitrite, (*M*) total nitrogen, (*N*) orthophosphate, and (*O*) total phosphorus for all study sites based on sampling period (for a given constituent, if a sampling period contains the same letter above it as another sampling period, there is no statistical difference between them at the 95 percent confidence level).—Continued

including assimilation and release by algae and aquatic plants; microbially mediated reactions like denitrification; adsorption and desorption processes; and exchange between streambed sediment and the overlying water column (Mulholland, 1992; McMahon and Böhlke, 1996; Mulholland and Hill, 1997; Mainstone and Parr, 2002; Dunne and Reddy, 2005). Interestingly, geochemically reducing conditions present in the buffer and hyporheic zones that help mitigate the amount of nitrate in groundwater discharged to the streams are the same conditions that can promote the mobilization and release of sorbed P from streambed deposits, including sediment derived from upland areas and decaying organic matter, into overlying stream water (Spruill, 2000; Spruill and others, 2005).

The results for nitrate+nitrite (fig. 7*L*) were notably different than the results for ammonia (fig. 7*J*) and organic N (fig. 7*K*). Nitrate+nitrite concentrations were substantially influenced by microbial denitrification, a process that reduces nitrate during anaerobic decomposition of organic matter. The median nitrate+nitrite concentration of 0.993 mg/L observed for February was substantially higher than the median concentrations for the other sampling periods, which ranged from <0.040 to 0.153 mg/L (table 11). The higher nitrate+nitrite concentrations for February coincided with higher streamflows and DO concentrations, and thus appear to reflect more overland contributions of nitrate in water from upstream field-drainage ditches to the streams, as well as less denitrification, for that period. These conditions are most likely to occur in the winter when the water table is high and the nitrate that is contributed to field ditches (from runoff, lateral groundwater inflows, and tile drainage) is likely to bypass the otherwise anoxic zones in near stream areas. Nitrate in the field ditches is rapidly carried to the main stem of the streams during high flows and is subject to less instream processing, including denitrification and uptake by plants and algae, when stream water temperatures are cold (fig. 7*A*) and DO concentrations are elevated (fig. 7*C*), as noted for the February sampling period. The lower nitrate+nitrite concentrations that occurred under the more reduced DO conditions during the June, August, October, and December sampling periods reflect a higher amount of denitrification. The highest median total N concentration of 1.6 mg/L also was observed for February (fig. 7*M*), reflecting the larger contribution from nitrate+nitrite compared to organic N, which constituted the more dominant fraction of total N among the other sampling periods.

Interestingly, sulfate (fig. 7*H*) had a similar distribution among the sampling periods as did both DO (fig. 7*C*) and nitrate+nitrite (fig. 7*L*). Sulfate concentrations were significantly higher during the February period. During the other periods with lower DO concentrations, sulfate apparently was reduced to other forms of sulfur.

In contrast to nitrate+nitrite, the median concentrations of ammonia (0.030 mg/L) and total organic N (0.56 mg/L) were lowest for the February period (fig. 7*J*, *K*; table 11). Similar to the seasonal pattern observed for water temperature (fig. 7*A*), median organic N concentrations were highest during the warm, growing-season months (June, August, and April) and steadily decreased through the fall and winter periods (October, December, and February). Organic N in streams occurs in both the dissolved form, such as urea, amino acids, and humic substances, and the particulate form, such as phytoplankton, zooplankton, microorganisms, and organic detritus. In this study, the dissolved organic N fraction was not measured. Therefore, the extent to which dissolved or particulate substances contributed to the organic nitrogen pool is not known. The observed pattern for total organic N is possibly influenced by algal and aquatic plant production, which likely would be higher during spring and summer and lower during the more dormant winter months.

Interesting differences among sampling periods also were noted for ortho-P (fig. 7*N*) and total P (fig. 7*O*). Overall concentrations for ortho-P (median of 0.009 mg/L) and total P (median 0.044 mg/L) were lowest in the February sampling period, the same period when the highest concentrations of nitrate+nitrite (fig. 7*L*) observed in the streams were attributed to increased overland transport of water through upstream field-drainage ditches. Concentrations of ortho-P and total P during the August period with higher flow conditions were not significantly different from the intermediate- or lower-flow sampling periods. In free-flowing streams with no point-source inputs, higher P concentrations in surface water tend to occur during higher streamflows in association with increased sediment inputs from overland runoff. In contrast, P patterns observed at the swampy, sluggish streams in this study area suggest that instream processes play a dominant role in P cycling. These processes may include adsorption/desorption processes and assimilation by aquatic plants, algae, and microbes in both the bed material and water column (Mainstone and Parr, 2002; Dunne and Reddy, 2005). The higher P concentrations observed during the more reduced DO conditions for the June, August, October, December, and April sampling periods possibly reflect higher amounts of algal biomass and (or) P releases into the water column from microbial degradation of organic matter and (or) desorption from organic substrates or anoxic bed sediments.

In summary, seasonal and hydrologic factors influenced water quality in these Coastal Plain agricultural watersheds. The differences noted among the sampling periods indicate that the interactions between seasonal climatic differences, streamflow conditions, and instream biotic and abiotic processes are complex and their integrated effects can have varying degrees of influence on individual nutrients. These findings are important to consider when developing studies to assess stream nutrient conditions in similar Coastal Plain settings and can inform the choice of specific objectives, nutrients to be examined, and overall timeline and frequency of sampling needed to capture seasonal and (or) hydrologic variability in the data.

Water-Quality Differences Related to Watershed Land-Use Type

Many of the water-quality properties and constituents were significantly influenced (ANOVA $P<0.05$) by watershed land-use type (table 10) on the basis of the results for all six sampling periods. Water-quality differences among the three land-use types, or groups (18 BK sites, 18 SW sites, and 18 SP sites), were examined to better understand potential CAFO influences. Statistical summaries, by land-use group, of the original (non-ranked transformed) water-quality data are provided in tabular (table 12) and graphical formats (fig. 8) to aid the discussion. Figure 8 includes box plots for properties and constituents with significant differences (ANOVA $P<0.05$) among land-use groups; results of the multiple-comparison tests among the groups are denoted along the top of the plots. No significant differences in water temperature, DO, calcium, total organic N, ortho-P, total P, and $\delta^{18}O$ of nitrate+nitrite were noted among the land-use types.

Significant differences were noted in specific conductance, pH, and all of the major ions, except calcium, among the land-use groups (table 10). Specific conductance, pH, magnesium, sodium, potassium, and chloride were significantly different between the BK and SW sites and the BK and SP sites, but not between the SW and SP sites (fig. 8*A–F*). Median specific conductance values for the SW and SP sites were higher than the BK sites, which reflects the higher median concentrations of dissolved magnesium, sodium, potassium, and chloride also noted at the SW and SP sites. Median pH values also were higher for the SW and SP sites relative to the BK sites. Sulfate (fig. 8*G*) for the SP sites was significantly different than both the BK and SW sites.

Median concentrations of ammonia+organic N, ammonia, and total N were higher at the SW and SP sites than at the BK sites (fig. 8*H*, *I*, and *K*; table 12). No significant difference in total organic N was noted among the land-use groups, suggesting that the differences in ammonia+organic N between the BK and SW sites and the BK and SP sites are associated with the ammonia fraction. Nitrate+nitrite was the only constituent found to be significantly different between all three land-use groups (fig. 8*J*). Median nitrate+nitrite concentrations progressively increase from the BK to the SW to the SP sites. Interestingly, no significant differences were identified for the P nutrients (ortho-P or total P) on the basis of land-use type (table 10).

Similar to the N constituents, median $\delta^{15}N$ values of nitrate+nitrite for the SW and SP sites were higher, or more positive, than the BK sites (fig. 8*L*), indicating that nitrate+nitrite at the SW and SP sites was more enriched in ^{15}N. The higher median $\delta^{15}N$ values of nitrate+nitrite likely indicate that N inputs to streams at the SW and SP sites were more influenced by animal-manure sources; however, it is important to note that other processes, such as denitrification and assimilation by algae, also may have influenced the observed $\delta^{15}N$ values of nitrate+nitrite.

These results indicate that waste-manure storage and (or) field applications at the CAFOs have increased surface-water concentrations of selected constituents at the SW and SP sites above those noted for the BK sites, which do not contain any active CAFOs. Although the various types and amounts of commercial fertilizer products used in the watersheds of the individual study sites are unknown, it is considered unlikely that the significant differences noted in the water-quality constituents would only occur between the BK group of sites and both CAFO site groups (SW and SP) and not between the SW and SP site groups if related solely to differences in commercial fertilizer use. Most of the statistically significant differences for major ions (magnesium, sodium, potassium, and chloride) and nutrients (ammonia+organic N, ammonia, nitrate+nitrite, and total N) occurred between the BK and SW sites and the BK and SP sites (fig. 8). The median concentrations of these constituents were all higher at the SW and SP sites relative to the BK sites.

It is unclear whether the lack of detectable differences in P among the land-use groups indicates that stream inputs of P were the same among the study watersheds with and without animal-waste manure applications or whether other environmental processes (like sediment deposition, adsorption/desorption, and assimilation) have obscured differences in source inputs of P derived from commercial fertilizer and (or) animal-waste manure.

Phosphorus, which is relatively immobile in soil, typically is transported to streams in particulate form during overland runoff. The more soluble N constituents, such as ammonia and nitrate+nitrite, are prone to leaching in soils and may be transported to streams through both groundwater discharge and overland runoff. The disparity between N and P response among the sites may reflect differences in transport pathways or instream processing that influenced instream concentrations of these two classes of nutrients.

Table 12. Statistical summary of water-quality properties and constituents by land-use type.

[diss., dissolved; mg/L, milligrams per liter; %, percent; µS/cm, microsiemens per centimeter; °C, degrees Celsius, N, nitrogen; P, phosphorus; O, oxygen; δ, delta; <, less than; ‰, per mil]

Chemical property or constituent (unit)	Background (BK) sites				Swine (SW) sites				Swine and poultry (SP) sites			
	Number of samples	Minimum	Median	Maximum	Number of samples	Minimum	Median	Maximum	Number of samples	Minimum	Median	Maximum
Water-quality properties												
Temperature, water (°C)	106	7.2	14.7	27.3	108	8.0	14.2	26.2	106	8.0	14.6	24.4
Specific conductance (µS/cm at 25 °C)	106	49	98	264	102	48	132	328	106	50	138	440
Oxygen, diss. (mg/L)	106	0.01	3.2	10.4	108	0.01	3.4	10.1	106	0.01	4.3	10.5
pH (standard units)	105	4.2	6.0	6.8	108	4.7	6.2	6.9	106	4.3	6.2	7.2
Major ions												
Calcium, diss. (mg/L)	106	1.73	6.92	15.9	102	1.94	8.52	19.7	106	2.34	7.16	43.9
Magnesium, diss. (mg/L)	106	1.45	2.64	4.61	102	0.76	3.34	7.74	106	0.92	3.76	11.3
Sodium, diss. (mg/L)	106	2.17	5.41	24.2	102	3.67	6.90	16.0	106	3.15	6.80	36.0
Potassium, diss. (mg/L)	106	0.60	3.90	15.6	102	0.90	6.84	24.9	106	1.41	6.58	46.2
Chloride, diss. (mg/L)	106	5.06	14.0	53.2	102	7.84	17.3	37.7	106	6.01	17.1	65.3
Sulfate, diss. (mg/L)	106	0.14	3.84	46.7	102	0.14	5.14	28.6	106	0.64	6.92	28.4
Nutrients												
Ammonia + organic N, total (mg/L as N)	106	0.36	0.83	2.3	108	0.32	0.94	4.8	106	0.16	0.96	7.4
Ammonia, diss. (mg/L as N)	106	<0.010	0.048	0.932	108	<0.010	0.102	3.42	106	<0.010	0.072	4.7
Total organic N (mg/L as N)	106	0.23	0.76	1.7	108	0.27	0.82	2.0	106	0.12	0.80	2.7
Nitrate + nitrite, diss. (mg/L as N)	106	<0.040	0.048	1.51	108	<0.04	0.173	15.9	106	<0.040	0.352	10.8
Total N (mg/L as N)	106	0.42	1.0	2.3	108	0.36	1.5	17.0	106	0.20	1.3	14.0
Ortho-phosphate, diss. (mg/L as P)	106	<0.004	0.026	0.713	108	<0.004	0.030	0.534	106	<0.004	0.026	0.466
Total P (mg/L as P)	106	0.015	0.098	1.14	108	0.009	0.122	0.981	106	0.012	0.100	0.860
Isotopes												
$\delta^{15}N$ of nitrate + nitrite (‰)	40	4.92	9.39	16.99	61	5.66	13.57	48.88	69	6.52	15.33	39.97
$\delta^{18}O$ of nitrate + nitrite (‰)	40	5.18	9.43	16.27	61	–1.39	8.48	22.98	69	0.29	9.04	21.33

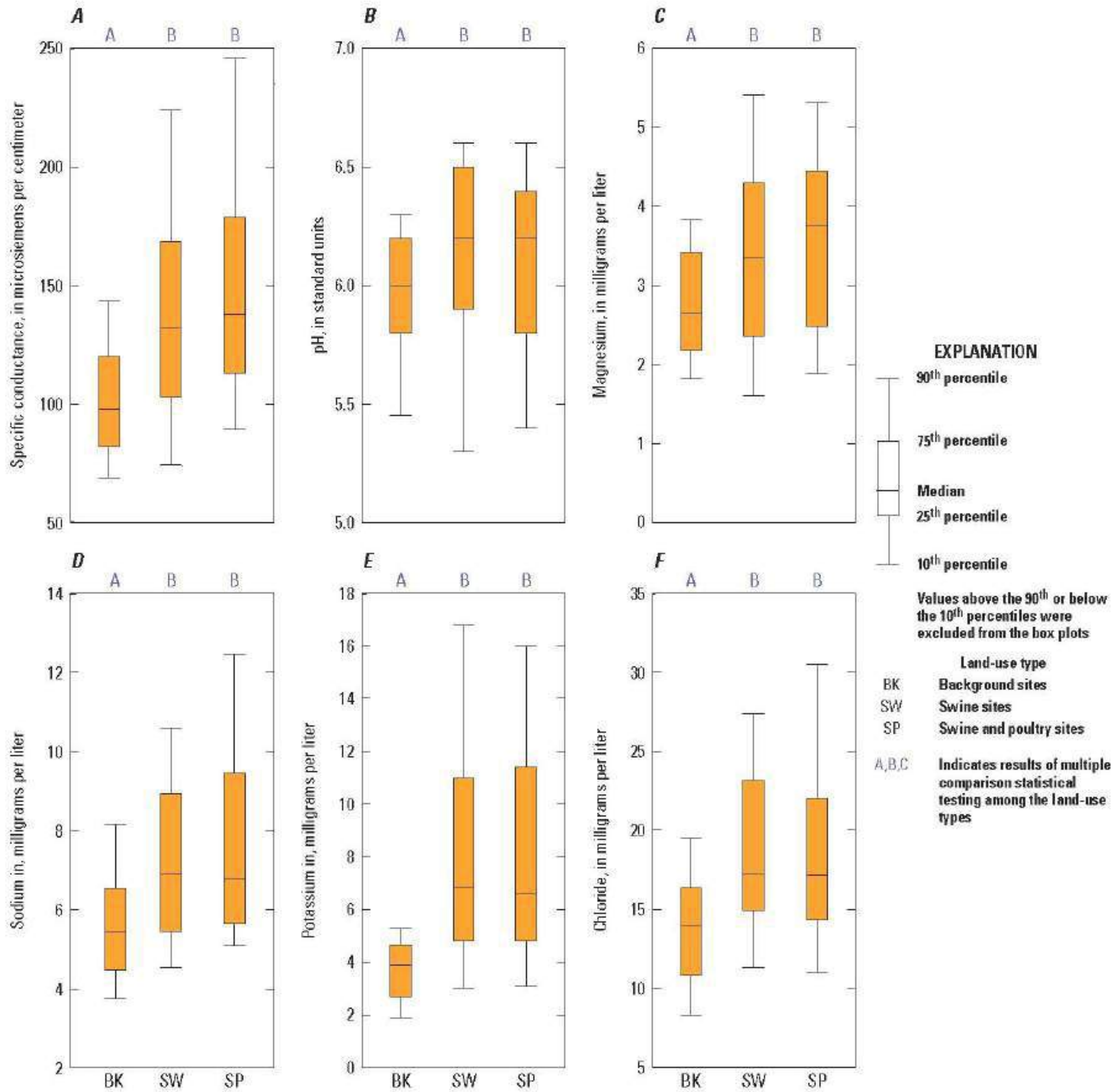


Figure 8. Distributions of (*A*) specific conductance, (*B*) pH, (*C*) magnesium, (*D*) sodium, (*E*) potassium, (*F*) chloride, (*G*) sulfate, (*H*) ammonia plus organic nitrogen, (*I*) ammonia, (*J*) nitrate plus nitrite, (*K*) total nitrogen, and (*L*) delta nitrogen-15 of nitrate plus nitrite for all sampling periods based on watershed land-use type (for a given constituent, if a land-use type contains the same letter above it as another land-use type, there is no statistical difference between them at the 95 percent confidence level).

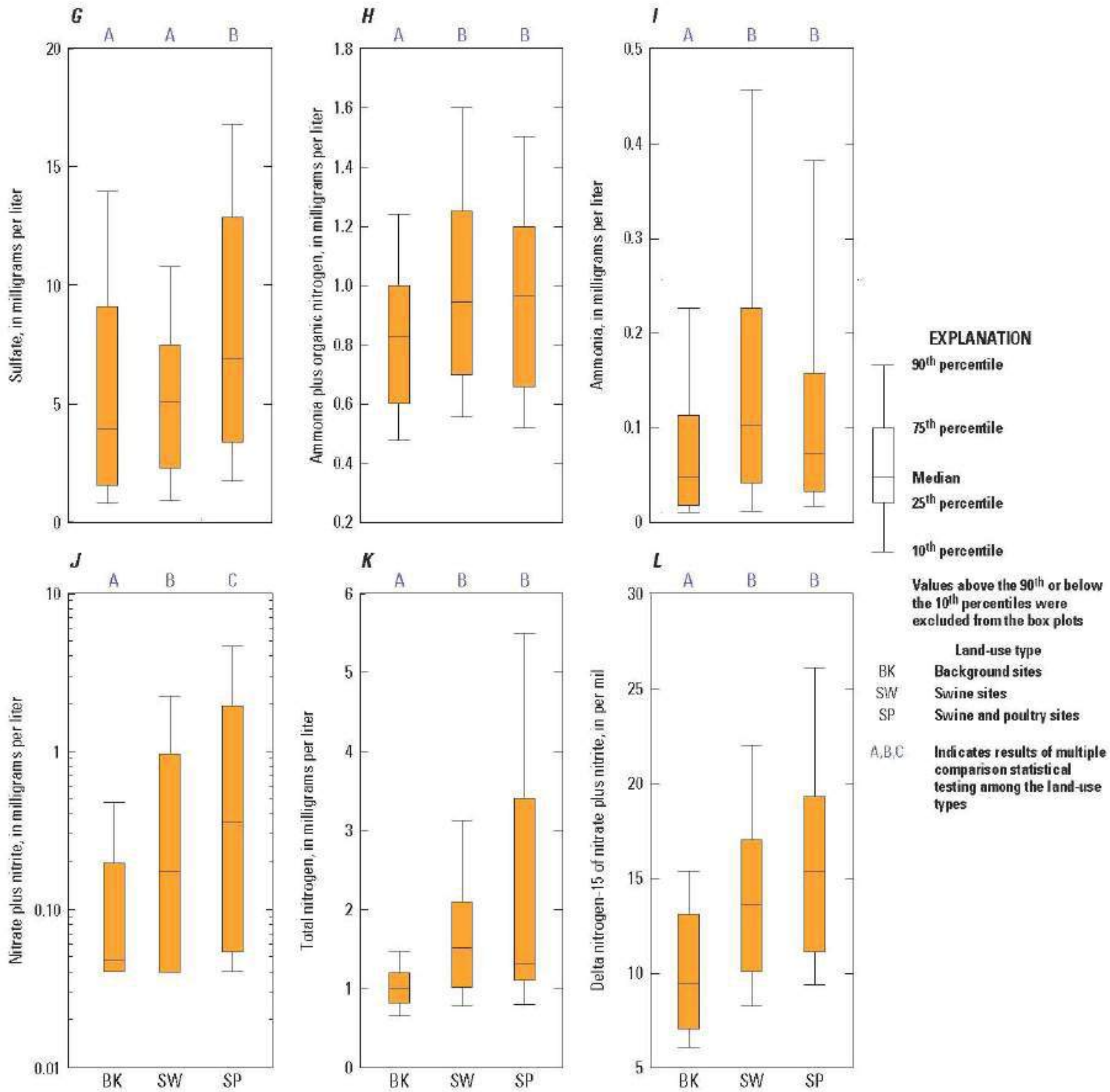


Figure 8. Distributions of (*A*) specific conductance, (*B*) pH, (*C*) magnesium, (*D*) sodium, (*E*) potassium, (*F*) chloride, (*G*) sulfate, (*H*) ammonia plus organic nitrogen, (*I*) ammonia, (*J*) nitrate plus nitrite, (*K*) total nitrogen, and (*L*) delta nitrogen-15 of nitrate plus nitrite for all sampling periods based on watershed land-use type (for a given constituent, if a land-use type contains the same letter above it as another land-use type, there is no statistical difference between them at the 95 percent confidence level)—Continued

Multi-Analyte Approach for Differentiating Sites With Water-Quality Effects From CAFOs

The statistical evaluations discussed previously indicated that when all 54 primary study sites were examined collectively on the basis of their land-use type (BK, SW, and SP), several water-quality differences related to animal-waste manures were identified for the SW and SP site groups. Interestingly, some individual SW and SP sites did not appear to be affected by animal-waste manures. Data were further evaluated to better understand distinctions among selected water-quality constituents at sites with and without CAFOs to aid identification of those SW and SP watersheds with measurable CAFO manure effects on water quality.

Insights Based on Multi-Site Reconnaissance Sampling Within Selected Watersheds During April 2013

During April 2013, samples were collected once at 23 secondary sites within 9 of the primary watersheds to obtain water-quality data from upstream reaches. These secondary sites were located in proximity to either swine CAFOs and spray fields or to background agricultural fields. Nutrient and ion concentrations and the nitrate+nitrite stable isotope data were evaluated to distinguish sites where CAFO waste manures did or did not have a measurable effect on surface-water quality.

Stable isotopes ($\delta^{15}N$ and $\delta^{18}O$) of nitrate are often used in water-quality studies as environmental tracers for investigating anthropogenic sources of nitrogen (such as atmospheric deposition, commercial inorganic fertilizers, and organic animal manures and septic wastes). Kendall and others (2007) diagrammed common ranges, or fields, of nitrate $\delta^{15}N$ and $\delta^{18}O$ values derived or nitrified from various N sources (fig. 9). The $\delta^{18}O$ values tend to be more useful for separating nitrate derived from atmospheric deposition or synthetic nitrate fertilizers from other sources. The $\delta^{15}N$ values tend to be more useful for distinguishing nitrate derived from microbial nitrification of ammonium and (or) organic N in fertilizer, precipitation, soil, and animal manure or human septic waste because these sources have overlapping $\delta^{18}O$ values, commonly between −10 and +15 ‰ (Kendall and others, 2007; Xue and others, 2009).

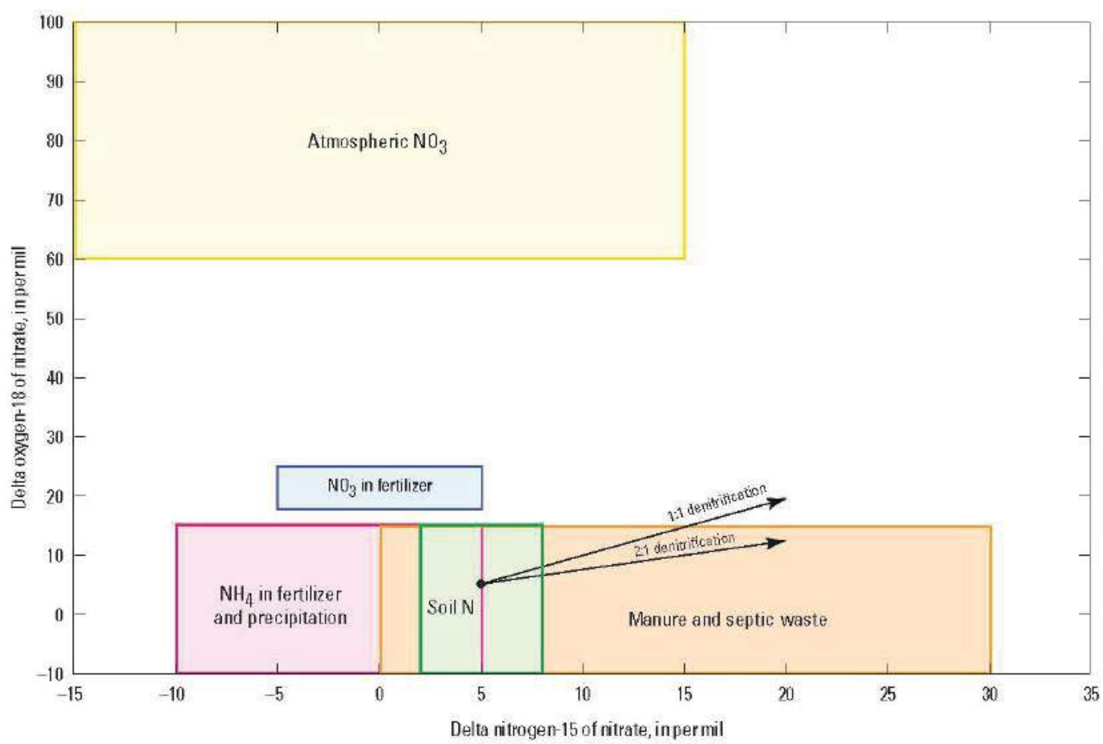


Figure 9. Common ranges in values of delta nitrogen-15 and delta oxygen-18 of nitrate derived from various nitrogen sources (modified from Kendall and others, 2007).

Inorganic fertilizers and animal-waste manures, which are the main sources of N in the agricultural watersheds in this study, generally have distinct $\delta^{15}N$ nitrate values (Kendall, 1998). The $\delta^{15}N$ values of nitrate originating from inorganic fertilizers typically are lower, about –5 to +5 ‰, than those from animal manures, which typically are higher and have a wider range of compositions, about 0 to +30 ‰ (Fogg and others, 1998; Kendall and others, 2007; Xue and others, 2009). Note that nitrate derived from human septic wastes generally has $\delta^{15}N$ values of about +5 to +20 ‰ that are indistinguishable from animal manures (Fogg and others, 1998; Xue and others, 2009); however, human-derived wastes are not considered to be a substantial contributor of N to streams in the study watersheds. Although the $\delta^{15}N$ values of soil nitrate derived from inorganic fertilizers tend to overlap those derived from the mineralization of natural soil organic N, about 0 to +8 ‰, they are often distinguishable from the higher nitrate $\delta^{15}N$ values associated with animal-waste manures (Fogg and others, 1998; Kendall and others, 2007; Xue and others, 2009).

Comparing measured nitrate $\delta^{15}N$ and $\delta^{18}O$ values in samples against the general source boxes depicted in figure 9 may be useful for assessing potential sources if the original source signal of the nitrate has not been substantially altered. Complications arise if the isotopic composition reflects a mixture of two or more nitrate sources and (or) has been influenced by biogeochemical processes, such as assimilation or denitrification, that transform N, which can cause the altered $\delta^{15}N$ and $\delta^{18}O$ values to resemble those of other sources (Kendall and others, 2007). During the process of denitrification, microbes preferentially use the lighter ^{14}N and ^{16}O isotopes, which enrich the remaining or residual nitrate pool with the heavier ^{15}N and ^{18}O isotopes, resulting in more positive nitrate $\delta^{15}N$ and $\delta^{18}O$ values. Denitrification causes coupled increases in the $\delta^{15}N$ and $\delta^{18}O$ values of the residual nitrate by an approximate 1:1 to 2:1 ratio (Böttcher and others, 1990; Kendall and others, 2007).

The effects of denitrification are illustrated using an example of assumed nitrate having an initial $\delta^{15}N$ value of 5 ‰ and $\delta^{18}O$ value of 5 ‰ similar to that derived from ammonium fertilizer or soil organic N (fig. 9). The two arrows indicate how the process of denitrification for nitrate with this initial isotopic signature produces residual nitrate $\delta^{15}N$ to $\delta^{18}O$ values that progressively increase along either a 1:1 denitrification line (having a slope of 1) or 2:1 denitrification line (having a slope of 0.5). As the $\delta^{15}N$ and $\delta^{18}O$ values of the initial nitrate reflecting an ammonium fertilizer or soil organic N source become increasingly more positive during denitrification, they become more similar to those expected for nitrate derived from animal-waste manures, thereby confounding interpretations of the nitrate sources.

These types of issues can make it complicated or impractical to identify nitrate sources solely on the basis of the nitrate isotopic compositions. It is beneficial to examine other chemical constituents in combination with the nitrate stable isotope data for differentiating sources of nitrate contamination in water (Spruill and others, 2002; Kendall and others, 2007; Xue and others, 2009). In the North Carolina Coastal Plain, Karr and others (2001) and Spruill and others (2002) used $\delta^{15}N$ data in combination with major ion data to examine sources of nitrate in groundwater. Karr and others (2001) used $\delta^{15}N$, potassium, and chloride data to examine swine-manure contamination in groundwater from a waste lagoon and spray field. Spruill and others (2002) evaluated the results of nitrate $\delta^{15}N$, nutrients (nitrate and ammonia) and major ions (calcium, magnesium, sodium, and potassium) with classification tree models to identify sources of groundwater nitrate derived from inorganic fertilizers, swine manure, poultry litter, and septic-system wastes. Ratios of selected ion concentrations (calcium to magnesium and sodium to potassium) and summed concentrations of sodium+potassium were found to be useful indicators for distinguishing the different nitrate sources.

The examination of the April 2013 water-quality data for the primary and secondary study sites primarily focused on evaluating nitrate+nitrite and sodium+potassium concentrations in combination with the nitrate+nitrite $\delta^{15}N$ values for differentiating those sites with measurable effects of CAFO manure on water quality (table 13). Comments on whether the surface-water samples that were collected had the potential to be influenced by one or more CAFOs upstream from the sites are noted in table 13. Detailed evaluations of the data for each group of associated sites are provided separately as appendix A5. Insights based on the evaluations of the April 2013 dataset (appendix A5) are discussed below.

In six of the nine watersheds that were examined, measured effects of swine CAFO manure on surface water at one or more upstream secondary sites also were noted further downstream at the primary site locations (table 13). The extent to which influences of CAFO manure may be identified in surface water at downstream watershed locations likely varies depending on the particular watershed setting, including such things as basin size, density of CAFOs and their locations, the presence or absence of tile drains and field ditches, stream morphology, and streamflow conditions. Many of the secondary sites that were located next to or downstream from swine CAFOs were found to be influenced by swine manure in terms of nitrate+nitrite and sodium+potassium concentrations and nitrate+nitrite $\delta^{15}N$ values. Conversely, no water-quality effect was noted at some of the sites (table 13), which suggests that all CAFOs do not necessarily have a measurable effect on these water-quality constituents in adjacent sections of streams.

The combined use of the nitrate+nitrite, sodium+potassium, and $\delta^{15}N$ of nitrate+nitrite data proved valuable for identifying those 9 primary and 23 secondary sites either having or not having a measurable water-quality effect associated with CAFO waste manures (appendix A5). Of the 32 sites, 18 had measurable manure influence, 11 had no measurable manure influence (including the 4 background agricultural sites), and 3 had unclear results (table 13). Distinctions among the results are illustrated in figure 10 for the sites with, without, or unclear CAFO manure influences. Boundaries delineating the general distribution in the

Table 13. Water-quality results for the April 2013 sample period used to examine waste-manure influences at the primary and secondary study sites.

[CAFO, concentrated animal feeding operation; mg/L, milligram per liter; $\delta^{15}N$, delta nitrogen-15; ‰, per mil; <, less than; na, not analyzed]

Study site (site maps in appendix A1)	Potential to be influenced by CAFOs	Dissolved oxygen (mg/L)	Nitrate + nitrite (mg/L)	Sodium + potassium (mg/L)	$\delta^{15}N$ of nitrate + nitrite (‰)	$\delta^{18}O$ of nitrate + nitrite (‰)	Are the results interpreted to reflect CAFO waste manure influences at the site? (see appendix A5)
SW-04A	Yes, near upgradient edge of swine spray field	6.3	0.307	7.96	15.80	11.09	Unclear
SW-04B	Yes, 1 swine CAFO	7.4	3.31	16.10	19.37	10.34	Yes
SW-04	Yes, 1 swine CAFO	3.4	1.09	16.66	22.16	10.62	Yes
SW-05A	Yes, 1 swine CAFO	0.08	0.052	10.01	na	na	No
SW-05B	No, background agricultural fields	4.2	1.70	7.28	9.66	8.43	No
SW-05C	Yes, 1 swine CAFO	5.4	3.40	19.16	21.68	10.78	Yes
SW-05	Yes, 4 swine CAFOs	2.9	0.795	12.42	17.05	8.87	Yes
SW-08A	Yes, 5 active and 1 inactive swine CAFOs	0.1	<0.040	16.41	na	na	Unclear
SW-08B	Yes, 1 swine CAFO	0.8	0.681	12.67	7.42	7.89	No
SW-08C	Yes, 3 swine CAFOs	4.0	1.22	16.40	24.56	10.05	Yes
SW-08D	No, background agricultural fields	6.3	2.74	9.95	5.44	6.27	No
SW-08	Yes, 12 active and 2 inactive swine CAFOs	0.02	<0.040	16.70	na	na	Unclear
SW-13A	Yes, 1 swine CAFO	5.9	35.4	65.70	18.92	9.95	Yes
SW-13B	Yes, 2 swine CAFOs	7.0	27.5	51.80	19.98	10.42	Yes
SW-13	Yes, 3 swine CAFOs	3.0	0.390	33.10	22.04	9.16	Yes
SP-01A	No, background agricultural fields	9.3	<0.040	5.19	na	na	No
SP-01B	Yes, 1 swine and 1 poultry CAFOs	10.6	<0.040	5.93	na	na	No
SP-01C	Yes, 2 swine CAFOs	11.8	0.592	31.10	27.99	9.74	Yes
SP-01	Yes, 6 swine and 1 poultry CAFOs	10.1	0.103	10.63	8.94	4.96	No
SP-04A	No, background agricultural fields	2.3	0.877	9.25	12.52	10.79	No
SP-04B	Yes, 2 swine and 1 poultry CAFOs	4.2	1.86	22.74	22.54	10.58	Yes
SP-04	Yes, 4 swine and 1 poultry CAFOs	2.1	0.110	21.24	17.01	9.58	Yes
SP-05A	Yes, 1 swine CAFO	7.1	3.50	12.06	7.93	5.20	No
SP-05B	Yes, 1 swine and 1 poultry CAFOs	9.2	2.62	12.16	8.75	6.91	No
SP-05	Yes, 1 swine and 3 poultry CAFOs	5.9	4.13	11.84	8.00	6.75	No
SP-09A	Yes, 3 swine and 1 poultry CAFOs	5.9	3.20	43.60	23.02	14.21	Yes
SP-09	Yes, 3 swine and 1 poultry CAFOs	5.4	1.94	33.70	23.13	14.72	Yes
SP-11A	Yes, 2 swine CAFOs	3.7	1.11	32.60	25.57	13.32	Yes
SP-11B	Yes, 4 swine CAFOs	1.4	1.73	32.50	28.96	9.67	Yes
SP-11C	Yes, 1 swine CAFO	9.5	2.98	12.66	11.91	8.63	Yes
SP-11D	Yes, 6 swine CAFOs	4.8	1.01	31.10	24.21	6.69	Yes
SP-11	Yes, 9 swine and 1 poultry CAFOs	0.3	<0.040	22.80	na	na	Yes

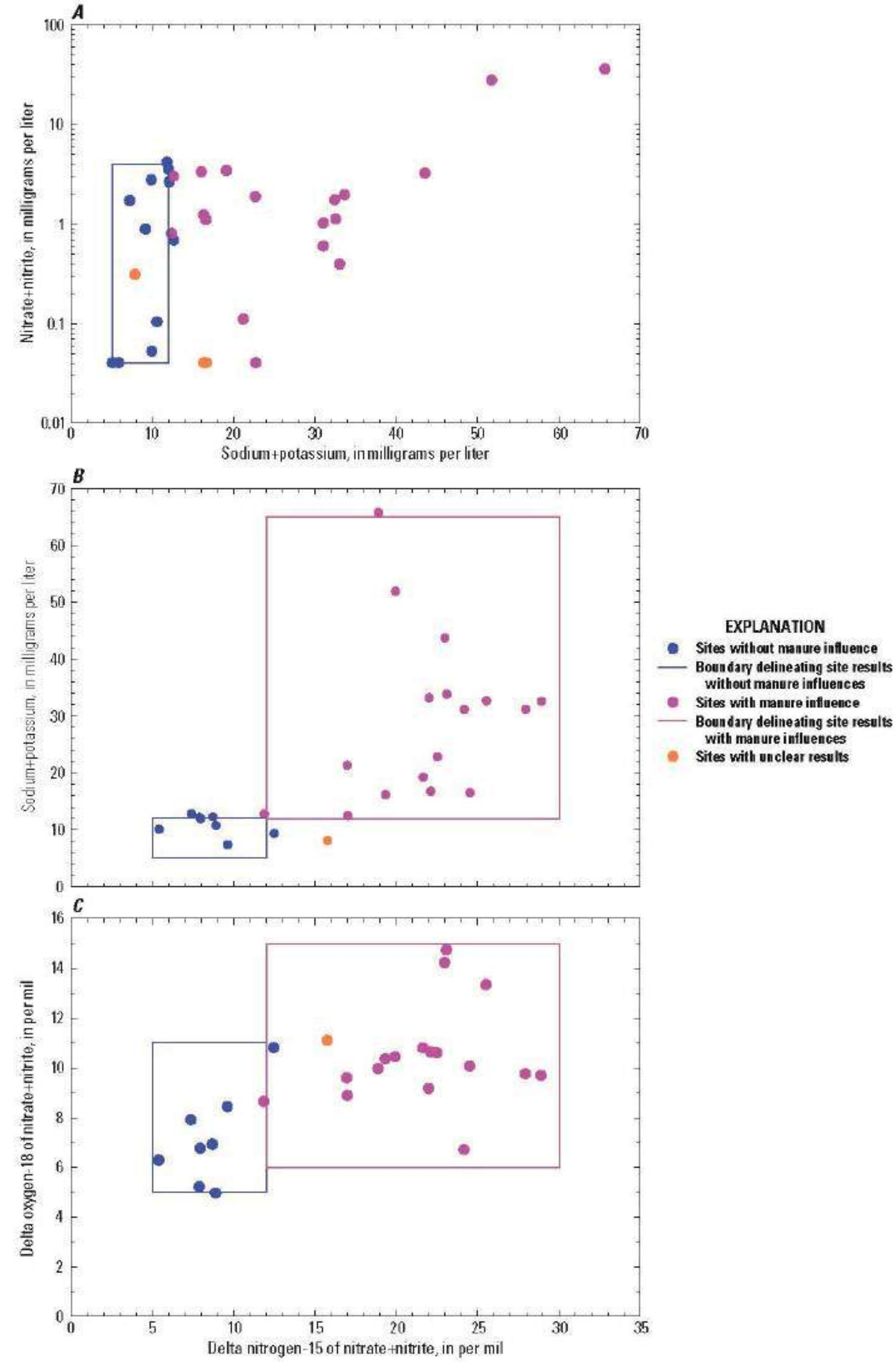


Figure 10. Graphs showing data comparisons of (*A*) sodium plus potassium to nitrate plus nitrite, (*B*) delta nitrogen-15 of nitrate plus nitrite to sodium plus potassium, and (*C*) delta nitrogen-15 to delta oxygen-18 of nitrate plus nitrite for sites with and without CAFO manure influences and sites with unclear results based on the April 2013 dataset.

sodium+potassium and nitrate+nitrite data for the sites without manure influences are shown in figure 10*A*. Boundaries delineating the general distributions in the nitrate+nitrite $\delta^{15}N$ and sodium+potassium data (fig. 10*B*) and the nitrate+nitrite $\delta^{15}N$ and $\delta^{18}O$ data (fig. 10*C*) are shown for both the sites without and with manure influences. The nitrate+nitrite $\delta^{15}N$ and $\delta^{18}O$ values for the sites without manure effects (fig. 10*C*) agree with the common $\delta^{15}N$ and $\delta^{18}O$ values of nitrate derived from ammonium fertilizer or natural soil organic N displayed in figure 9. The nitrate+nitrite $\delta^{15}N$ and $\delta^{18}O$ values for the sites with manure effects (fig. 10*C*) also agree with the $\delta^{15}N$ and $\delta^{18}O$ values of nitrate commonly derived from animal manure sources (fig. 9).

The overall range of nitrate+nitrite concentrations was fairly similar for the sites with and without manure influences; however, sodium+potassium concentrations were higher for the sites with a manure influence than those without an influence (fig. 10*A*). Better separation among the sites is noted in the nitrate+nitrite $\delta^{15}N$ and sodium+potassium data (fig. 10*B*). The sites without manure influences had lower $\delta^{15}N$ values (about 5 to 12 ‰) and sodium+potassium concentrations (about 5 to 12 mg/L) than the manure influenced sites, which are characterized by higher $\delta^{15}N$ values (about 12 to 30 ‰) and sodium+potassium concentrations (about 12 to 65 mg/L). Comparison of the nitrate+nitrite $\delta^{15}N$ to $\delta^{18}O$ data (fig. 10*C*) indicates that although the $\delta^{15}N$ values appear to segregate, the sites without and with manure influences tend to have overlapping $\delta^{18}O$ values of about 5 to 11 ‰ and 6 to 15 ‰, respectively. For several sites, limited or inconsistent results made it difficult to determine whether water quality reflected background agricultural conditions or waste-manure effects. For example, the unclear results shown for some sites included a sodium+potassium concentration within the range of sites without manure influences (fig. 10*A*, *B*) but the elevated $\delta^{15}N$ value (fig. 10*B*, *C*) could be indicative of either a manure signature or denitrification effects on soil nitrate derived from inorganic fertilizer or natural organic N.

Identification of Study Watersheds Having Measurable CAFO Effects on Water Quality

On the basis of the insights gained from the above evaluation of the April 2013 dataset, nitrate+nitrite and sodium+potassium concentrations and the nitrate+nitrite isotopic values ($\delta^{15}N$ and $\delta^{18}O$) for all 6 sampling periods at the 54 primary study sites (appendix A6) were evaluated to determine which of the 18 SW and 18 SP sites had apparent CAFO waste-manure effects on stream water quality. Results for the 18 BK study sites first were plotted to serve as a baseline, or background, dataset (fig. 11) against which the SW and SP site data could be compared. The reference boundaries determined for sites without and sites with measurable manure influences using the April 2013 dataset (fig. 10) also were included in figure 11 to aid examination of the results.

Overall, the baseline results for the BK sites fall within fairly well-defined clusters (fig. 11). Most of the nitrate+nitrite and sodium+potassium concentrations for the BK sites fall within the reference boundary for sites without waste-manure effects. Note that many of the BK sites had nitrate+nitrite concentrations less than the RL of 0.04 mg/L. As previously discussed, denitrification is one of the important factors known to influence nitrate+nitrite concentrations at the study sites. The effects of denitrification are evident in the background nitrate+nitrite $\delta^{15}N$ results. The BK sites had nitrate+nitrite $\delta^{15}N$ values, up to about 17 ‰, that extended beyond the upper limit of about 12 ‰ for the reference boundary for sites without manure influences (fig. 11*B*). The nitrate+nitrite $\delta^{15}N$ and $\delta^{18}O$ values for the BK sites plot along a best-fit regression line having a slope of 0.48 (fig. 11*C*), which is indicative of denitrification that causes coupled increases in the $\delta^{15}N$ to $\delta^{18}O$ values by a 2:1 ratio. Increased isotopic values resulting from denitrification explains why some of the BK sites, with no waste-manure influences, had nitrate+nitrite $\delta^{15}N$ and $\delta^{18}O$ values within the reference boundary reflecting manure influence.

Data for each of the SW and SP sites were plotted and compared against the figure 11 boundaries respresenting the BK site baseline data, as well as the sites without and with measurable manure influences, to categorize those SW and SP sites with results that (1) were similar to background conditions, or (2) had distinct differences indicating CAFO manure effects. It was impractical to include all of the comparison plots in the report. Therefore, for illustrative purposes, representative plots for selected sites with results similar to background conditions are shown in figure 12, and selected sites with results indicating manure influences are shown in figure 13.

Sites SW-14, SW-16, SP-05, and SP-15 had results similar to background conditions based on comparisons of their sodium+potassium to nitrate+nitrite concentrations (fig. 12*A*), nitrate+nitrite $\delta^{15}N$ values to sodium+potassium concentrations (fig. 12*B*), and nitrate+nitrite $\delta^{15}N$ to $\delta^{18}O$ values (fig. 12*C*). The effects of denitrification can also be seen in the $\delta^{15}N$ results for site SP-15.

The effects of CAFO waste manures are indicated in some or all of the results for sites SW-04, SW-05, SP-12, and SP-16 as compared to the reference boundaries (fig. 13). Sites SW-05 and SP-16 had samples with results overlapping background conditions as well as manure influences. These site results likely reflect different instream mixtures of groundwater and overland runoff from areas with and without CAFOs where at times manure influences on water quality were not always evident. CAFO manure effects were evident in all of the sample results for sites SW-04 and SP-12 (fig. 13). Site SP-12, located immediately downstream from multiple swine CAFO waste-manure lagoons and application fields (appendix fig. A1-48), had high nitrate+nitrite $\delta^{15}N$ and $\delta^{18}O$ values. The isotopic signatures of nitrate+nitrite derived from waste manures at this site possibly reflect the effects of different fractionation processes, such as ammonia volatilization and denitrification, that occurred before, during, and (or) after the applications of waste manures from the storage lagoons to the spray fields.

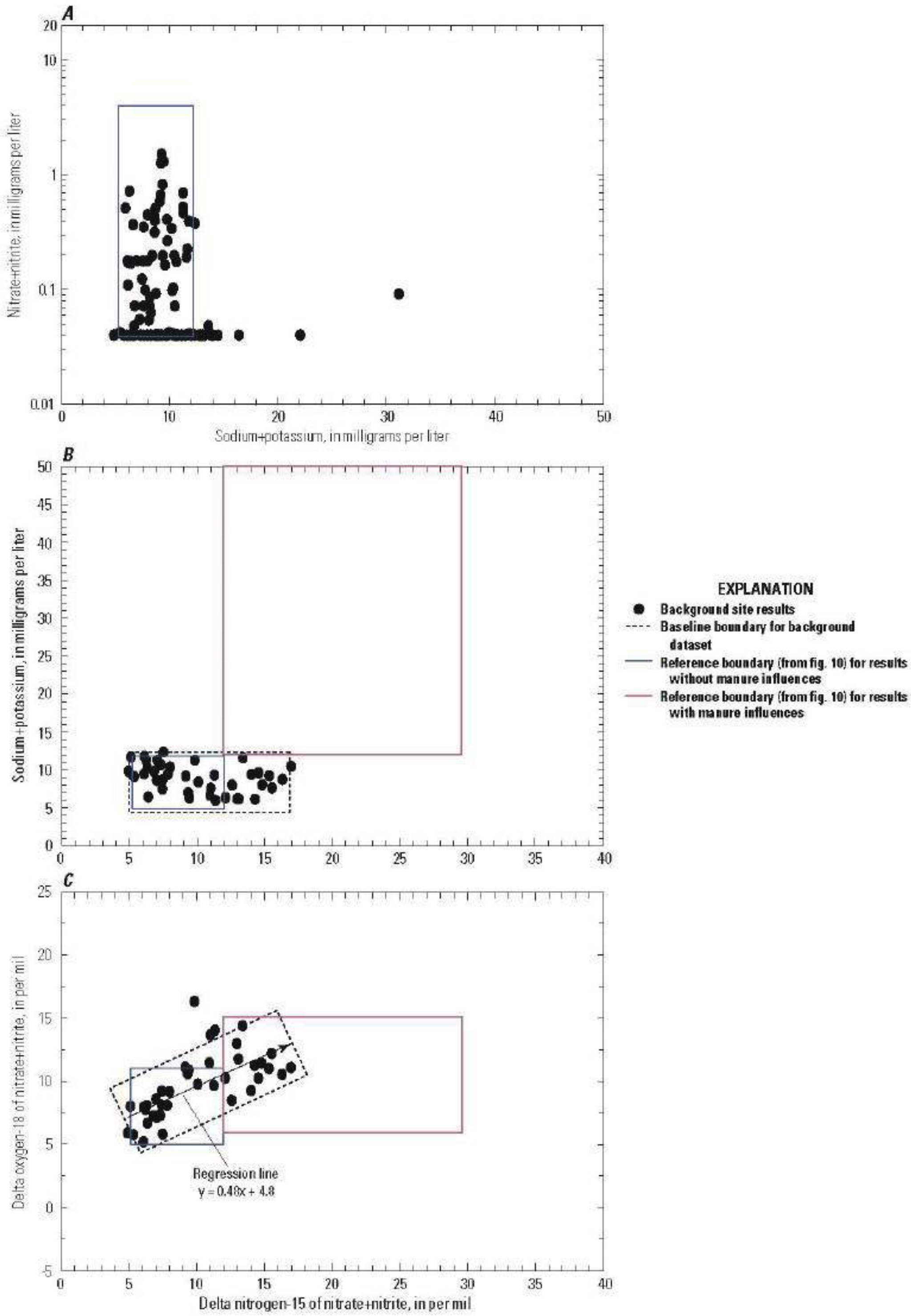


Figure 11. Graphs showing data comparisons of (*A*) sodium plus potassium to nitrate plus nitrite, (*B*) delta nitrogen-15 of nitrate plus nitrite to sodium plus potassium, and (*C*) delta nitrogen-15 to delta oxygen-18 of nitrate plus nitrite for the background sites.

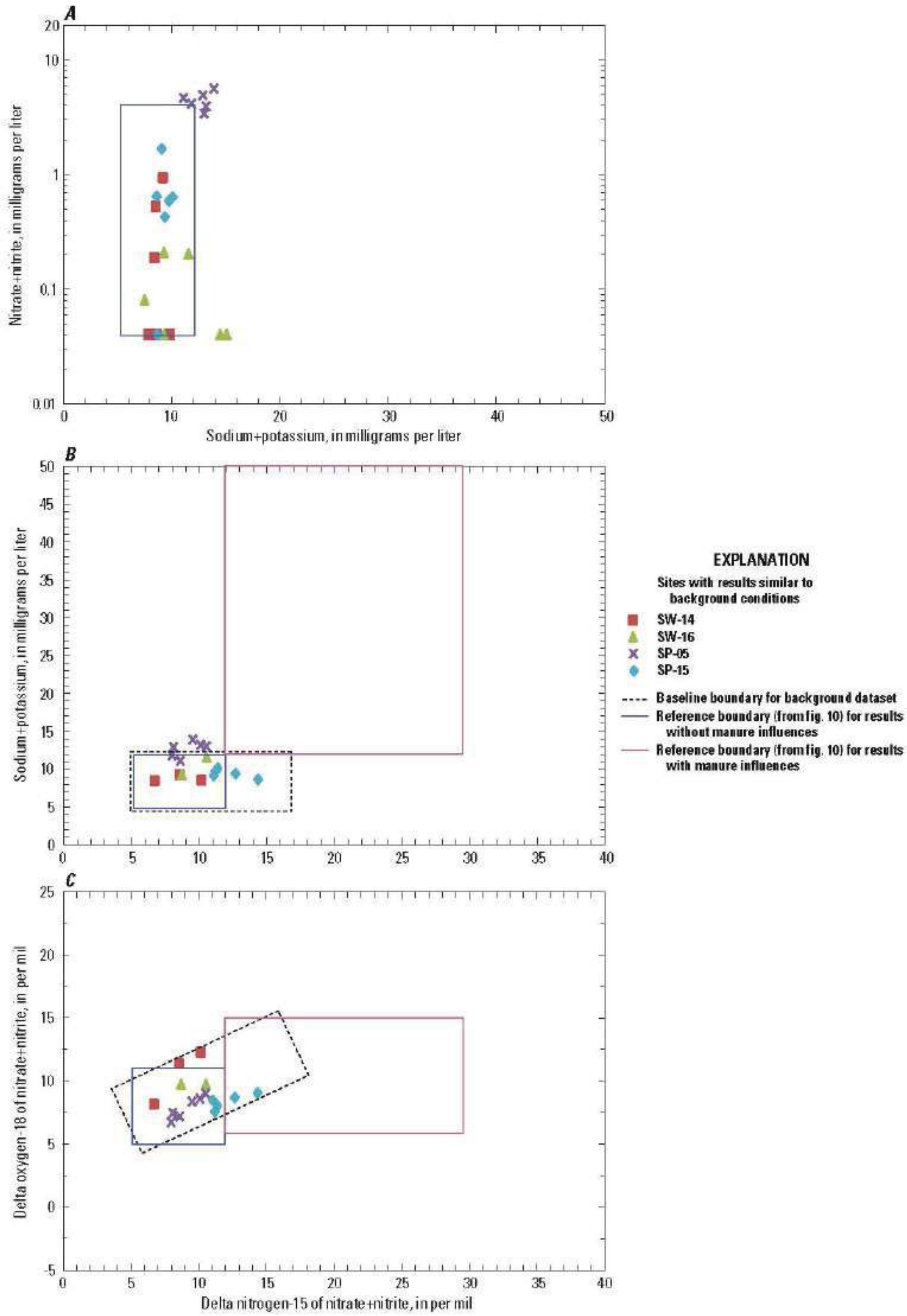


Figure 12. Graphs showing data comparisons of (*A*) sodium plus potassium to nitrate plus nitrite, (*B*) delta nitrogen-15 of nitrate plus nitrite to sodium plus potassium, and (*C*) delta nitrogen-15 to delta oxygen-18 of nitrate plus nitrite at four representative sites (SW-14, SW-16, SP-05, and SP-15) with results similar to background conditions.

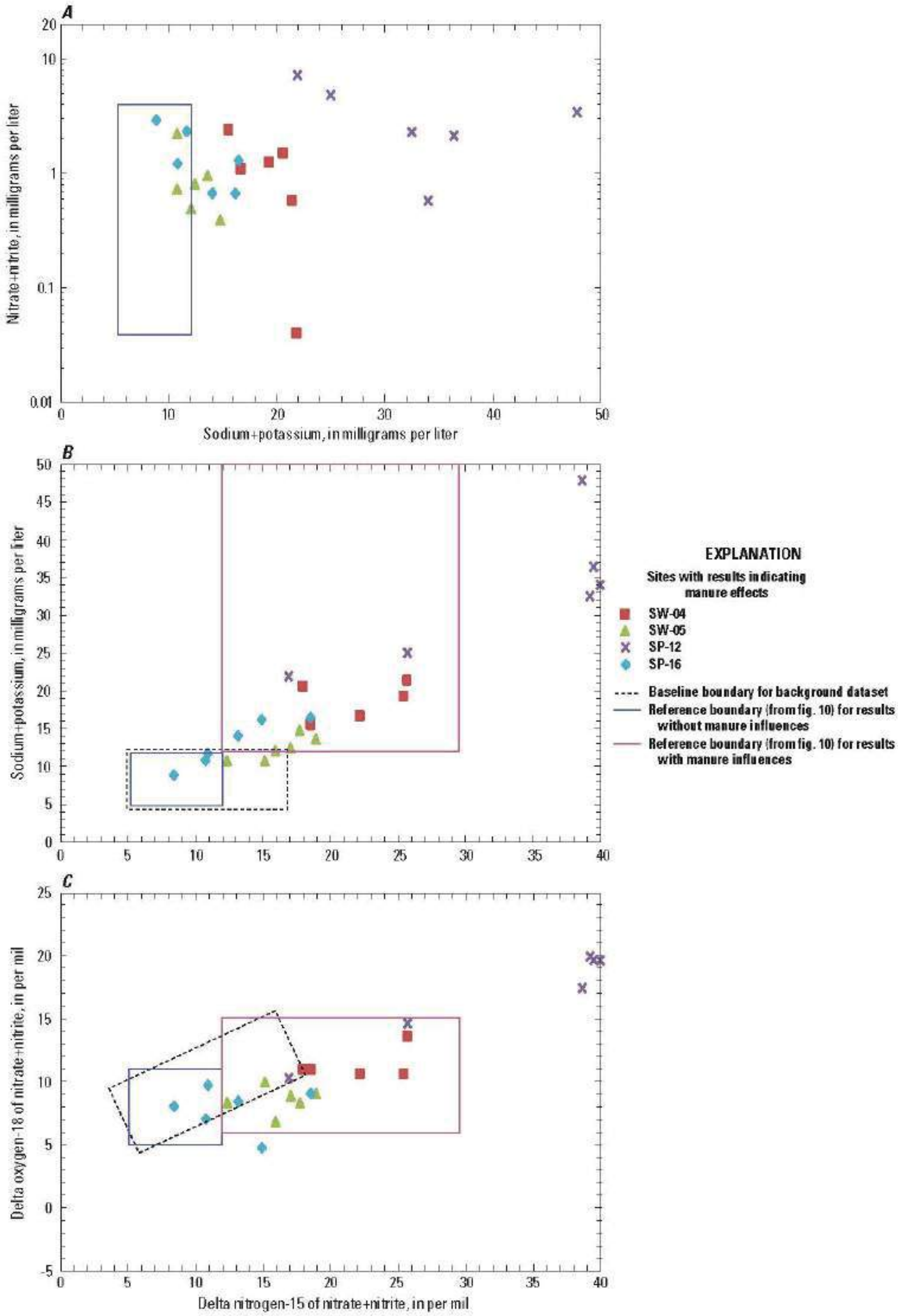


Figure 13. Graphs showing data comparisons of (*A*) sodium plus potassium to nitrate plus nitrite, (*B*) delta nitrogen-15 of nitrate plus nitrite to sodium plus potassium, and (*C*) delta nitrogen-15 to delta oxygen-18 of nitrate plus nitrite at four representative sites (SW-04, SW-05, SP-12, and SP-16) with results indicating manure effects.

On the basis of the comparisons of sodium+potassium concentrations, nitrate+nitrite concentrations, and the $\delta^{15}N$ and $\delta^{18}O$ of nitrate+nitrite values, 10 of the 36 CAFO sites (28 percent) had results similar to background conditions, and 21 of the sites (58 percent) had results with measurable CAFO manure effects (table 14). Note that the identification of those SW or SP watersheds as being similar to background conditions does not necessarily imply that CAFOs in those watersheds have no local influence on water quality, only that no distinction was noted at the watershed sampling location for the constituents that were examined. Three of the SW sites (SW-03, SW-08, and SW-15) and two of the SP sites (SP-03 and SP-08) had limited or indeterminate results for determining whether they were similar to background or manure influenced; these sites with unclear results were excluded from further evaluation.

The manure-influenced group of sites tended to have distinctly higher sodium+potassium concentrations (commonly between 11 and 33 mg/L) and $\delta^{15}N$ values of nitrate+nitrite (commonly between 11 and 26 ‰) relative to both the background and similar to background groups of sites, which commonly had sodium+potassium concentrations between 6 and 14 mg/L and $\delta^{15}N$ values of nitrate+nitrite between 6 and 15 ‰ (table 14; appendix A6). Based on the six sampling periods from June 2012 to April 2013, sodium+potassium concentrations and $\delta^{15}N$ values of nitrate+nitrite appear to be useful water-quality indicators for differentiating streams with measurable CAFO manure effects. It would be beneficial to base future similar analyses on a larger number of samples that more fully reflect hydrologic and seasonal variability in water-quality conditions among sites of interest.

Table 14. Statistical summary of selected water-quality constituents for the background sites, CAFO sites with results similar to background conditions, and CAFO sites with results reflecting manure influences.

[diss., dissolved; mg/L, milligrams per liter; N, nitrogen; O, oxygen; +, plus; <, less than; δ, delta; ‰, per mil]

Chemical constituent (unit)	Background sites[1]				Similar to background sites[2]				Manure-influenced sites[3]			
	Number of samples	10th percentile	Median	90th percentile	Number of samples	10th percentile	Median	90th percentile	Number of samples	10th percentile	Median	90th percentile
Sodium + potassium, diss. (mg/L)	106	6.35	9.23	12.9	54	6.48	9.57	14.5	124	10.8	16.66	32.7
Nitrate + nitrite, diss. (mg/L as N)	106	<0.040	0.048	0.505	60	<0.040	0.074	3.41	124	<0.040	0.692	4.27
$\delta^{15}N$ of nitrate + nitrite (‰)	40	6.08	9.39	15.10	27	7.33	6.74	12.42	95	10.80	16.28	25.70
$\delta^{18}O$ of nitrate + nitrite (‰)	40	6.26	9.43	13.29	27	4.96	2.54	11.42	95	6.50	9.16	14.62

[1]The background, or baseline, dataset includes the results of all 18 BK sites (BK-01 through BK-18).

[2]The sites with results deemed to be similar to background conditions include 6 SW sites (SW-02, 06, 07, 10, 14, and 16) and 4 SP sites (SP-01, 05, 15, and 17).

[3]The sites with results deemed to reflect manure influences include 9 SW sites (SW-01, 04, 05, 09, 11, 12, 13, 17, and 18) and 12 SP sites (SP-02, 04, 06, 07, 09, 10, 11, 12, 13, 14, 16, and 18).

Watershed Attributes Associated With CAFO Water-Quality Effects

Watershed environmental attributes were compared among the study sites with and without CAFO manure influences (see previous section). The five sites (SW-03, 08 and 15, and SP-03 and 08) with indeterminate results were not included in this analysis. The remaining 49 sites were grouped into three response categories: 18 background sites; 10 similar to background CAFO sites, and 21 manure-influenced CAFO sites. A classification tree model was developed to examine relations between selected watershed environmental variables and the three response categories (appendix A7).

The main intent in this analysis was to identify key differences in watershed characteristics associated with sites either having or not having measurable CAFO manure effects. Watershed characteristics analyzed as predictor (independent) variables in the model included drainage area size, land cover (percentages of forested land, cropland, grassland, and wetlands), soil drainage (percentages of HSGs total A, total B, total C, and D), swine CAFO attributes, and poultry CAFO attributes (appendix A7). The swine CAFO attributes included the total number of permitted active swine CAFOs, total swine barns and barn density, total swine and swine density, total swine weight and weight density, total acres available for applying swine-waste manure and acre density, and total generated PAN for each watershed site. The poultry CAFO attributes available for examination with the classification tree analysis were limited to the total number of identified poultry CAFOs, total poultry barns, and poultry barn density for each site. Results of the classification tree analysis, including the splits in the tree model, the selected environmental variable and value defining each split, and the response category with the number of sites classified in each category, are illustrated in figure 14 and summarized in table 15.

Table 15. Classification tree model results for the 49 study sites.

[#, number; <, less than; ≥, greater than or equal to; >, greater than; mi², square mile; %, percent; na; not applicable]

Split	Predictor variable and split value	Response category (# of sites)	Number of misclassified sites	Identity of misclassified sites (actual category)
1	Total active swine CAFOs < 1	Background group (18)	0 of 18	na
1 2	Total active swine CAFOs ≥ 1 Swine barn density > 2.9 barns/mi²	Manure-influenced group 1 (15)	0 of 15	na
1 2 3	Total active swine CAFOs ≥ 1 Swine barn density < 2.9 barns/mi² Wetlands > 14.4 %	Similar to background group 1 (7)	0 of 7	na
1 2 3 4	Total active swine CAFOs ≥ 1 Swine barn density < 2.9 barns/mi² Wetlands < 14.4 % Total acres available for applying swine-waste manure > 52.4	Manure-influenced group 2 (5)	0 of 5	na
1 2 3 4	Total active swine CAFOs ≥ 1 Swine barn density < 2.9 barns/mi² Wetlands < 14.4 % Total acres available for applying swine-waste manure < 52.4	Similar to background group 2 (4)	1 of 4	SP-10 (Manure influenced)

The tree model selected the presence/absence of active swine CAFOs, swine barn density, percentage of wetlands, and acres available for applying swine-waste manure as the best discriminators, or predictor variables, for classifying the study sites among the background, similar to background, and manure-influenced response categories or groups (fig. 14; table 15). The model was highly successful in accurately classifying the sites into the appropriate response categories. Only 1 of the 49 sites was misclassified (table 15). The first, or primary, split in the tree model was based on the presence/absence of active swine CAFOs in the watersheds (fig. 14). All 18 of the BK sites were placed in the background group because none of the BK sites contain any active swine CAFOs.

Interestingly, the 15 SW sites and 16 SP sites, which all had at least 1 active swine CAFO, were further differentiated into two groups for the manure-influenced category (referred to as manure-influenced groups 1 and 2) and two groups for the similar to background category (referred to as similar to background groups 1 and 2) on the basis of subsequent splits in swine barn density, percentage of wetlands, and total acres available for applying swine-waste manure (fig. 14; table 15). The splits among these four groups indicate how variations in these particular swine CAFO and land-cover variables may inhibit or promote the ability of the watersheds to mitigate manure effects on water quality in streams receiving inputs from swine CAFO application fields.

When swine barn density in the watersheds was greater than 2.9 barns/mi^2, 15 sites (7 SW and 8 SP sites) with measurable CAFO manure effects on water quality were correctly placed in manure-influenced group 1 (fig. 14). The SW and SP sites in manure-influenced group 2 and similar to background groups 1 and 2 all had swine barn densities that were less than 2.9 barns/mi^2 (fig. 14; table 15). Seven sites (4 SW and 3 SP sites) without measurable CAFO manure effects on water quality were correctly placed in similar to background group 1 when the amount of wetlands in the watershed was greater than 14.4 percent. In comparing manure-influenced group 1 to similar to background group 1 (fig. 14), the SW and SP sites with measurable CAFO manure effects had higher swine barn densities (median of 4.8 barns/mi^2), more acres available for applying swine manure (median of 243.7 acres), and less wetlands (median of 12.1 percent) relative to the SW and SP sites without measurable CAFO manure effects. Similar to background group 1 had lower swine barn densities (median of 1.2 barns/mi^2), fewer acres available for applying swine manure (median of 66.9 acres), and more wetlands (median of 20.8 percent).

When both swine barn density was less than 2.9 barns/mi^2 and wetlands was less than 14.4 percent, the SW and SP sites with or without measurable CAFO manure effects were separated on the basis of the total acres available for applying swine-waste manure in the watersheds (fig. 14; table 15). Five sites (2 SW and 3 SP sites) were correctly placed in manure-influenced group 2 when total acres available were greater than 52.4; four sites (2 SW and 2 SP sites) were placed in similar to background group 2 when total acres available were less than 52.4 (fig. 14). Similar to background group 2 contained misclassified site SP-10, which actually belongs to the manure-influenced category (table 15). Site SP-10 had a swine barn density of 2.7 barns/mi^2, just below the split value of 2.9 barns/mi^2, wetlands of 8.7 percent, and total available acres of 39.2, which resulted in its placement in similar to background group 2. The sites in manure-influenced group 2 and similar to background group 2 had comparable median values of swine barn density (2.2 and 2.5 barns/mi^2, respectively) and wetlands (11.7 and 8.4 percent, respectively). The primary distinction between these groups is that the total available acres for applying swine manure for the sites in manure-influenced group 2 (median of 164.1 acres) were about 5 times higher than the total available acres for the sites in similar to background group 2 (median of 34.0 acres).

The classification tree analysis, as well as the other data evaluations in this report, indicate that land-applications of waste manure at swine CAFOs had an effect on water-quality conditions in streams at many, but not all, of the SW and SP study sites. Measurable effects of CAFO waste manures on stream water quality were most evident in those SW and SP watershed study sites having lower percentages of wetlands combined with higher swine barn densities and (or) higher total acres available for applying waste manure at the swine CAFOs. Conversely, the SW and SP watersheds with stream water quality similar to background agricultural conditions were associated with lower swine barn densities combined with higher percentages of wetlands or lower total acres available for applying waste manure at the swine CAFOs.

None of the poultry CAFO attributes examined with the tree model were selected as predictor variables for identifying differences between the sites with and without CAFO manure effects. This should not be misconstrued to indicate that poultry CAFO manures do not have an influence on stream water quality but rather may be a function of the limited poultry CAFO attribute data that were available for examination, as well as the nature of the watershed sites selected for this study, which had a primary emphasis on swine CAFOs. Thirteen of the 16 SP study sites included in the classification tree analysis (appendix A7) had substantially more swine barns (ranging from 4 to 59) than poultry barns (ranging from 1 to 8) in the watersheds. These watersheds likely received larger proportions of land-applied swine manure relative to poultry litter. Additional water-quality data, as well as more detailed information on poultry CAFO attributes (such as the types and numbers of poultry raised), from watersheds only containing poultry CAFOs would allow further comparisons to swine-only watersheds to better understand whether swine manure and poultry litter have similar or different effects on water quality.

The classification tree model provides a useful approach for exploring potential CAFO manure effects in similar, small (1 to 18 mi^2) Coastal Plain watersheds where water-quality data are lacking. Potential sites could be screened on the basis of the influential watershed attributes (swine barn density, acres available for applying swine manure, and percentage of wetlands) identified by the model. Results could help water-resource managers and researchers identify streams with high potential for manure influences on water quality in order to prioritize them for further investigation and (or) targeted best management practices. The classification tree model can be refined as additional CAFO attribute information and water-quality data become available, both for existing study sites as well as new locations. The inclusion of data on specific manure-disposal practices at both swine and poultry CAFOs (including specific application fields and the frequency, timing, and amounts of applied manures) would enhance understanding of the effects of swine and poultry waste manures on stream water quality in different agricultural settings of the North Carolina Coastal Plain.

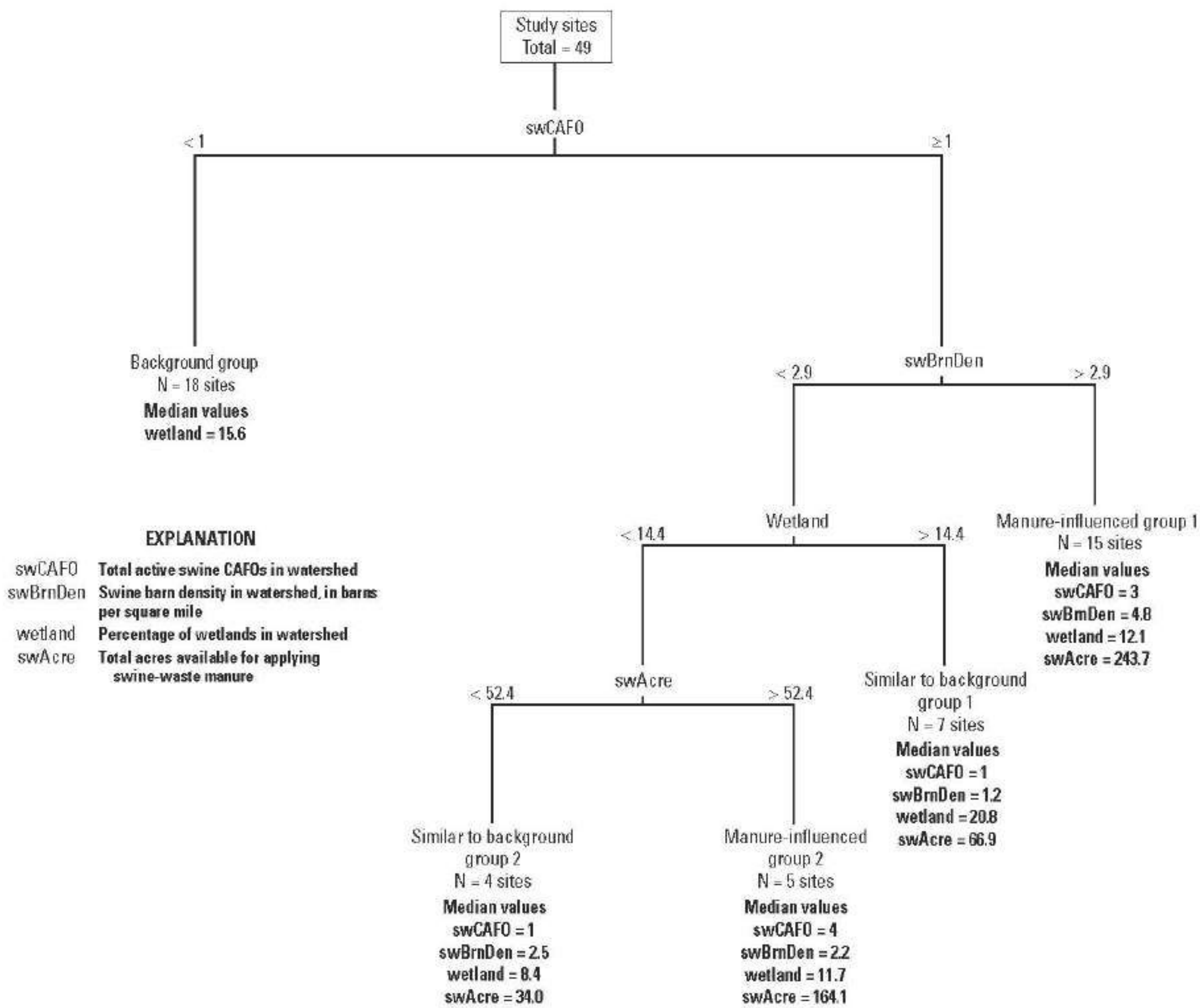


Figure 14. Classification tree model identifying the environmental predictor variables that best classified the 49 examined sites among the background, similar to background, and manure-influenced response categories.

Summary and Conclusions

Water quality was evaluated at 54 agricultural stream sites in the North Carolina Coastal Plain for the period June 2012 through April 2013. Water-quality data and detailed watershed attributes were collected, compiled, and statistically analyzed to determine differences among streams draining watersheds with and without land-applied CAFO waste manures. Three general watershed land-use types, or groups, were examined during the study, including 18 background watersheds with no active CAFOs (BK sites), 18 watersheds with one or more active swine CAFOs but no poultry CAFOs (SW sites), and 18 watersheds with at least one active swine CAFO and one active dry-litter poultry CAFO (SP sites). The watersheds had drainage areas ranging from 1.2 to 17.5 mi^2 and land cover was composed predominantly of cropland, forests, and wetlands. Most watersheds had low gradient, swampy floodplain streams that were typically characterized by slow velocities, high organic matter, and relatively low dissolved oxygen. None of the watersheds contained permitted point-source discharge facilities, cattle CAFOs, or wet-poultry CAFOs. Conventional fertilizers used for crop production were the primary source of nutrients at the BK sites. Animal-waste manures applied to agricultural fields associated with the swine or poultry CAFOs represented additional sources of nutrients at the SW and SP study sites.

Water-quality data included field measurements of water temperature, specific conductance, pH, and dissolved oxygen, and laboratory analyses of major ions, nutrients, and stable isotopes. Samples were collected at the 54 primary sites during 6 bimonthly sampling periods from June 2012 to April 2013. An additional 23 secondary sites within 9 of the primary watershed sites were sampled once during April 2013 to provide additional data at stream sites directly adjacent or in close proximity to swine CAFOs and (or) background agricultural areas. Regional precipitation and streamflow data, along with δ^2H and $\delta^{18}O$ isotopic results for precipitation and stream samples, were used to assess general hydrologic conditions during the sampling periods.

ANOVA and multiple-comparison statistical tests were performed to characterize differences in stream water quality among the six sampling periods and the three (BK, SW, and SP) watershed land-use types. Most of the water-quality properties and constituents varied significantly among sampling periods, changing both seasonally and in response to hydrologic conditions. Nutrient differences among the sampling periods indicate that the relations between seasonal climatic differences, streamflow conditions, and instream biotic and abiotic processes are complex, and their integrated effects can have varying degrees of influence on individual nutrients in different watersheds. These findings are important to consider when developing approaches to assess stream nutrient conditions in similar Coastal Plain settings and can inform the development of sampling strategies that capture seasonal and (or) hydrologic variability. For example, the highest median concentrations of dissolved oxygen and nitrate+nitrite were observed during February 2013, when higher streamflows appeared to reflect more overland contributions of nitrate from upstream field-drainage ditches. Nitrate in the field ditches is carried to the main stem of the streams during higher flows and is subject to less instream processing, including denitrification and assimilation, when stream water temperatures are colder and dissolved oxygen concentrations are elevated. Nitrate+nitrite tended to be lowest during warm and dry sampling periods, when conditions were favorable for denitrification. In contrast, median concentrations of ammonia, total organic N, ortho-P, and total P were lowest during February. Environmental factors that likely influenced the various forms and instream concentrations of the N and P constituents include assimilation and release by algae and aquatic plants, redox conditions, microbially mediated reactions, adsorption and desorption processes, and biogeochemical exchange between streambed sediment and the overlying water column.

Water quality also varied significantly among the three watershed land-use types. Median values of specific conductance, several major ions (magnesium, sodium, potassium, and chloride), and nitrogen fractions (ammonia+organic N, ammonia, nitrate+nitrite, total N, and $\delta^{15}N$ of nitrate+nitrite) were higher for the SW and SP land-use groups as compared to the BK group, which have no active CAFOs. The higher concentrations of these constituents reflect the influence of swine-waste manure storage or applications at the SW sites and swine- and (or) poultry-waste manure storage or applications at the SP sites. No significant differences in water temperature, dissolved oxygen, calcium, total organic N, ortho-P, total P, or $\delta^{18}O$ of nitrate+nitrite were noted among the land-use groups. The disparity observed between N and P response among the site groups may reflect differences in transport pathways or instream processing that influenced instream concentrations of these two classes of nutrients. When comparing the land-use groups, there was an overall measurable effect of animal-waste manures on stream water quality for the SW and SP watersheds relative to the BK watersheds; however, this does not mean that CAFO waste manures had an observable effect on water-quality conditions at every SW and SP site. Additional evaluations were performed on the water-quality data to distinguish those SW and SP sites where effects of CAFO waste manures were evident.

At the majority of individual SW and SP watersheds, measurable CAFO effects on water quality were clearly distinguished. At other sites, effects were less evident. Elevated concentrations of nitrate+nitrite did not necessarily indicate a CAFO effect; conversely, low nitrate+nitrite concentrations did not necessarily indicate the absence of a CAFO effect. An integrated evaluation of nitrate+nitrite concentrations, sodium+potassium concentrations, and stable isotopes ($\delta^{15}N$ and $\delta^{18}O$) of nitrate+nitrite was used to differentiate which SW and SP sites did or did not have a CAFO waste-manure signature.

Streams with CAFO manure effects typically had higher sodium+potassium concentrations (commonly between 11 and 33 mg/L) and $\delta^{15}N$ values of nitrate+nitrite (commonly between 11 and 26 ‰) relative to streams reflecting background agricultural conditions, which commonly had sodium+potassium concentrations between 6 and 14 mg/L and $\delta^{15}N$ values of nitrate+nitrite between 6 and 15 ‰. Denitrification affected the $\delta^{15}N$ and $\delta^{18}O$ signatures of nitrate+nitrite at some sites and must be accounted for during interpretations of nutrient sources.

As part of the evaluation, individual SW and SP sites were differentiated into two groups, including (1) those with results that were similar to background conditions, and (2) those with results reflecting CAFO waste-manure effects. Ten of the 36 SW and SP sites (28 percent) had water quality similar to background conditions. Twenty-one of the SW and SP sites (58 percent) had distinct water-quality differences, reflecting swine- and (or) poultry CAFO manure effects. Five of the SW and SP sites (14 percent) had limited or indeterminate results for determining whether they were similar to background or manure influenced; these sites were omitted from further evaluation. On the basis of the results of this study, it is apparent that land-applications of waste manure at swine CAFOs influenced ion and nutrient chemistry in many of the North Carolina Coastal Plain streams that were studied. In particular, sodium+potassium concentrations coupled with $\delta^{15}N$ values of nitrate+nitrite were useful water-quality indicators for distinguishing sites with measurable CAFO manure effects.

Relations in watershed environmental attributes among the similar to background and manure-influenced site groups were examined through classification tree analysis. The classification tree model identified swine barn density, percentage of wetlands, and total acres available for applying swine-waste manures as the best discriminators, or predictor variables, for classifying sites among the similar to background and manure-influenced groups. Variations in these particular attributes appeared to influence those watersheds where CAFO effects on water quality were either evident or mitigated. Measurable effects of CAFO waste manures on stream water quality were most evident in those SW and SP watersheds having lower percentages of wetlands combined with higher swine barn densities and (or) higher total acres available for applying waste manure at the swine CAFOs. Stream water quality was similar to background agricultural conditions in SW and SP watersheds with lower swine barn densities coupled with higher percentages of wetlands or lower acres available for swine manure applications.

The classification tree model provides a useful approach for examining potential CAFO manure effects on stream water quality among similar Coastal Plain watersheds, including those where water-quality data are lacking. The model can serve as an exploratory tool to identify watersheds that might warrant further examination and (or) targeted best management practices. The study model can be refined as additional watershed attribute information and water-quality data become available. Additional water-quality data, poultry CAFO attribute data, and information on manure disposal practices at both swine and poultry CAFOs would enhance scientific understanding of the effects of swine and poultry waste manures on stream water quality under different agricultural settings.

References Cited

American Public Health Association, 1998, Standard methods for the examination of water and wastewater (20th ed.): Washington, D.C., American Public Health Association, American Water Works Association, and Water Environment Federation, Method 3120, p. 3–37 to 3–43.

Barker, J.C., Zublena, J.P., and Walls, F.R., 1994, Animal and poultry manure production and characterization: North Carolina State University, Department of Biological and Agricultural Engineering, accessed May 5, 2014, at http://www.bae.ncsu.edu/topic/animal-waste-mgmt/program/land-ap/barker/a&pmp&c/content.htm.

Bonn, B.A., 2008, Using the U.S. Geological Survey National Water Quality Laboratory LT-MDL to evaluate and analyze data: U.S. Geological Survey Open-File Report 2008–1227, 73 p.

Böttcher, J., Strebel, O., Voerkelius, S., and Schmidt, H.L., 1990, Using isotope fractionation of nitrate-nitrogen and nitrate-oxygen for evaluation of microbial denitrification in a sandy aquifer: Journal of Hydrology, v. 114, p. 413–424.

Breiman, L., Friedman, J.H., Olshen, R.A., and Stone, C.J., 1984, Classification and regression trees: Boca Raton, Fla., Chapman & Hall/CRC, 368 p.

Burkholder, J.M., Dickey, D.A., Kinder, C.A., Reed, R.A., Mallin, M.A., McIver, M.R., Cahoon, L.B., Melia, G., Brownie, C., Smith, J., Deamer, N., Springer, J., Glasgow, H.B., and Toms, D., 2006, Comprehensive trend analysis of nutrients and related variables in a large eutrophic estuary—A decadal study of anthropogenic and climatic influences: Limnology and Oceanography, v. 51, p. 463–487.

Burkholder, J.M., and Glasgow, H.B., Jr., 1997, *Pfiesteria piscicida* and other *Pfiesteria*-like dinoflagellates—Behavior, impacts and environmental controls: Limnology and Oceanography, v. 42, p. 1052–1075.

Burkholder, J.M., Glasgow, H.B., Jr., and Hobbs, C.W., 1995, Distribution and environmental conditions for fish kills linked to a toxic ambush predator dinoflagellates: Marine Ecology Progress Series, v. 124, p. 43–61.

Casciotti, K.L., Böhlke, J.K., McIlvin, M.R., Mroczkowski, S.J., and Hannon, J.E., 2007, Oxygen isotopes in nitrite: analysis, calibration, and equilibration: Analytical Chemistry, v. 79, p. 2427–2436.

Casciotti, K.L., and McIlvin, M.R., 2007, Isotopic analyses of nitrate and nitrite from reference mixtures and application to Eastern Tropical North Pacific waters: Marine Chemistry, v. 107, p. 184–201.

Casciotti, K.L., Sigman, D.M., Galanter Hastings, M., Böhlke, J.K., and Hilkert, A., 2002, Measurement of the oxygen isotopic composition of nitrate in seawater and freshwater using the denitrifier method: Analytical Chemistry, v. 74, p. 4905–4912.

Copeland, Claudia, 2010, Animal waste and water quality—EPA regulation of concentrated animal feeding operations (CAFOs): Washington, D.C., Congressional Research Service Report RL31851, 21 p.

Coplen, T.B., Qi, Haiping, Révész, Kinga, Casciotti, Karen, and Hannon, J.E., 2012, Determination of the $\delta^{15}N$ and $\delta^{18}O$ of nitrate in water; RSIL lab code 2900, chap. 17 *of* Stable isotope-ratio methods, sec. C *of* Révész, Kinga, and Coplen, T.B., eds., Methods of the Reston Stable Isotope Laboratory (slightly revised from version 1.0 released in 2007): U.S. Geological Survey Techniques and Methods, book 10, 35 p., accessed May 11, 2015, at http://pubs.usgs.gov/tm/2006/tm10c17/.

Crouse, D.A., and Shaffer, K., 2011, SoilFacts—Guidelines for the commercial application of poultry litter: North Carolina Cooperative Extension Service Publication AG-439-76W, accessed June 19, 2013, at http://www.soil.ncsu.edu/publications/extension.htm.

David, M.B., Gentry, L.E., Kovacic, D.A., and Smith, K.M., 1997, Nitrogen balance in and export from an agricultural watershed: Journal of Environmental Quality, v. 26, p. 1038–1048.

Dukes, M.D., and Evans, R.O., 2006, Impact of agriculture on water quality in the North Carolina Middle Coastal Plain: Journal of Irrigation and Drainage Engineering, v. 132, p. 250–262.

Dunne, E.J., and Reddy, R.K., 2005, Phosphorus biogeochemistry of wetlands in agricultural watersheds, *in* Dunne, E.J., Reddy, K.R., and Carton, O.T., eds., Nutrient management in agricultural watersheds—A wetlands solution: The Netherlands, Wageningen Academic Publishers, p. 105–119.

Evans, R.O., Gilliam, J.W., and Skaggs, R.W., 1991, Controlled drainage management guidelines for improving drainage water quality: Raleigh, North Carolina Cooperative Extension Service, Bulletin AG-443.

Evans, R.O., Westerman, P.W., and Overcash, M.R., 1984, Subsurface drainage water quality from land application of swine lagoon effluent: Transactions of the American Society of Agricultural Engineers, v. 27, no. 2, p. 473–478.

Fishman, M.J., ed., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93–125, 217 p.

Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.

Fogg, G.E., Rolston, D.E., Decker, D.L., Louie, D.T., and Grismer, M.E., 1998, Spatial variation in nitrogen isotope values beneath nitrate contamination sources: Ground Water, v. 36, no. 3, p. 418–426.

Fry, J., Xian, G., Jin, S., Dewitz, J., Homer, C., Yang, L., Barnes, C., Herold, N., and Wickman, J., 2011: Completion of the 2006 national land cover database for the conterminous United States, Photogrammetric Engineering & Remote Sensing, v. 77, no. 9, p. 858–864.

Gilliam, J.W., Osmond, D.L., and Evans, R.O., 1997, Selected agricultural best management practices to control nitrogen in the Neuse River basin: Raleigh, North Carolina State University, North Carolina Agricultural Research Service Technical Bulletin 311.

Glasgow, H.B., and Burkholder, J.M., 2000, Water quality trends and management implications from a five-year study of a eutrophic estuary: Ecological Applications, v. 10, no. 4, p. 1024–1046.

Harden, S.L., 2008, Microbial and nutrient concentration and load data during stormwater runoff at a swine concentrated animal feeding operation in the North Carolina Coastal Plain, 2006–2007: U.S. Geological Survey Open-File Report 2008–1156, 22 p.

Harden, S.L., Cuffney, T.F., Terziotti, Silvia, and Kolb, K.R., 2013, Relation of watershed setting and stream nutrient yields at selected sites in central and eastern North Carolina, 1997–2008: U.S. Geological Survey Scientific Investigations Report 2013–5007, 47 p.

Harden, S.L., and Spruill, T.B., 2004, Ionic composition and nitrate in drainage water from fields fertilized with different nitrogen sources, Middle Swamp Watershed, North Carolina, August 2000–August 2001: U.S. Geological Survey Scientific Investigations Report 2004–5123, 14 p.

Harden, S.L., and Spruill, T.B., 2008, Factors affecting nitrate delivery to streams from shallow ground water in the North Carolina Coastal Plain: U.S. Geological Survey Scientific Investigations Report 2008–5021, 39 p.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: Elsevier, 522 p. (Also available online as U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chap. A3 (2002), accessed February 2014 at http://pubs.usgs.gov/twri/twri4a3/html/pdf.html.)

Hubbard, R.K., Newton, G.L., and Hill, G.M., 2004, Water quality and the grazing animal: Journal of Animal Science, v. 82, p. E255–E263.

Huffman, R.L., 2004, Seepage evaluation of older swine lagoons in North Carolina: Transactions of the American Society of Agricultural Engineers, v. 47, no. 5, p. 1507–1512.

Hunt, P.G., Stone, K.C., Humenik, F.J., and Rice, J.M., 1995, Impact of animal waste on water quality in an eastern Coastal Plain watershed, in Steele, K., ed., Animal waste and the land-water interface: Chelsea, Mich., Lewis Publishers, p. 257–264.

Israel, D.W., Showers, W.J., Fountain, M., and Fountain, J., 2005, Nitrate movement in shallow ground water from swine-lagoon-effluent spray fields managed under current application regulations: Journal of Environmental Quality, v. 34, p. 1828–1842.

Jaynes, D.B., Colvin, T.S., Karlen, D.L., Cambardella, C.A., and Meek, D.W., 2001, Nitrate loss in subsurface drainage as affected by nitrogen fertilizer rate: Journal of Environmental Quality, v. 30, p. 1305–1314.

Karr, J.D., Showers, W.J., Gilliam, W., and Andres, A.S., 2001, Tracing nitrate transport and environmental impact from intensive swine farming using delta nitrogen-15: Journal of Environmental Quality, v. 30, p. 1163–1175.

Kendall, C., 1998, Tracing nitrogen sources and cycling in catchments, *in* Kendall, C., and McDonnell, J.J., eds., Isotope tracers in catchment hydrology: Amsterdam, Elsevier, p. 519–576.

Kendall, C., and Coplen, T.B., 2001, Distribution of oxygen-18 and deuterium in river waters across the United States: Hydrological Processes, v. 15, p. 1363–1393.

Kendall, C., Elliott, E.M., and Wankel, S.D., 2007, Tracing anthropogenic inputs of nitrogen to ecosystems, *in* Michener, R.H., and Lajtha, K., eds., Stable isotopes in ecology and environmental science, : Malden, Mass., Blackwell Publishing, p. 375–449.

Korom, S.F., 1992, Natural denitrification in the saturated zone—A review: Water Resources Research, v. 41, p. 1657–1668.

Luettich, R.A., McNinch, J.E., Paerl, H., Peterson, C.H., Wells, J.T., Alperin, M., Martens, C.S., and Pinckney, J.L., 2000, Neuse River estuary modeling and monitoring project stage 1—Hydrography and circulation, water column nutrients and productivity, sedimentary processes and benthic-pelagic coupling, and benthic ecology: The University of North Carolina Water Resources Research Institute, Report 325-B.

Mainstone, C.P., and Parr, W., 2002, Phosphorus in rivers—Ecology and management: The Science of the Total Environment, v. 282–283, p. 25–47.

Mallin, M.A., and Cahoon, L.B., 2003, Industrialized animal production—A major source of nutrient and microbial pollution to aquatic ecosystems: Population and Environment, v. 24, no. 5, p. 369–385.

McMahon, G., and Lloyd, O.B., Jr., 1995, Water-quality assessment of the Albemarle-Pamlico drainage basin, North Carolina and Virginia—Environmental setting and water-quality issues: U.S. Geological Survey Open-File Report 95–136, 72 p.

McMahon, P.B., and Böhlke, J.K., 1996, Denitrification and mixing in a stream-aquifer system—Effects on nitrate loading to surface water: Journal of Hydrology, v. 186, p. 105–128.

Mulholland, P.J., 1992, Regulation of nutrient concentrations in a temperate forest stream—Roles of upland, riparian, and instream processes: Limnology and Oceanography, v. 37, p. 1512–1526.

Mulholland, P.J., and Hill, W.R., 1997, Seasonal patterns in streamwater nutrient and dissolved organic carbon concentrations—Separating catchment flow path and in-stream effects: Water Resources Research, v. 33, p. 1297–1306.

Nelson, N.O., Parsons, J.E., and Mikkelsen, R.L., 2005, Field-scale evaluation of phosphorus leaching in acid sandy soils receiving swine waste: Journal of Environmental Quality, v. 34, p. 2024–2035.

North Carolina Department of Agriculture and Consumer Services, 2012, 2012 Agricultural statistics: North Carolina Department of Agriculture and Consumer Services, Agricultural Statistics Division, accessed June 18, 2013, at http://www.ncagr.gov/stats/index.htm.

North Carolina Division of Water Resources, 2013, Animal Feeding Operations, Facility Map, List of Permitted Animal Facilities: North Carolina Department of Environment and Natural Resources Division of Water Resources, accessed January 2013, at http://portal.ncdenr.org/web/wq/animal-facility-map.

North Carolina Floodplain Mapping Program, 2012, Floodplain Mapping Information System, accessed January 2012, at http://www.ncfloodmaps.com/.

Novak, J.M., Watts, D.W., Hunt, P.G., and Stone, K.C., 2000, Phosphorus movement through a Coastal Plain soil after a decade of intensive swine manure application: Journal of Environmental Quality, v. 29, no. 4, p. 1310–1315.

Osmond, D.L., and Kang, J., 2008, SoilFacts, Nutrient removal by crops in North Carolina: North Carolina Cooperative Extension Service Publication AG-439-16W, accessed June 19, 2013, at http://www.soil.ncsu.edu/publications/extension.htm.

Paerl, H.W., Valdes, L.M., Joyner, A.R., and Piehler, M.F., 2004, Solving problems resulting from solutions—Evolution of a dual management strategy for the eutrophying Neuse River estuary, North Carolina: Environmental Science and Technology, v. 38, p. 3068–3073.

Patton, C.J., and Kryskalla, J.R., 2011, Colorimetric determination of nitrate plus nitrite in water by enzymatic reduction, automated discrete analyzer methods: U.S. Geological Survey Techniques and Methods, book 5, chap. B8, 34 p.

Patton, C.J., and Truitt, E.P., 2000, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of ammonium plus organic nitrogen by a Kjeldahl digestion method and an automated photometric finish that includes digest cleanup by gas diffusion: U.S. Geological Survey Open-File Report 00–170, 31 p.

Puckett, L.J., 2004, Hydrogeologic controls on the transport and fate of nitrate in ground water beneath riparian buffer zones–Results from thirteen studies across the United States: Water Science and Technology, v. 49, no. 3, p. 47–53.

Randall, G.W., and Mulla, D.J., 2001, Nitrate nitrogen in surface waters as influenced by climatic conditions and agricultural practices: Journal of Environmental Quality, v. 30, p. 337–344.

Révész, Kinga, and Coplen, T.B., 2008a, Determination of the $\delta(^{2}H/^{1}H)$ of water—RSIL lab code 1574, chap. C1 *of* Révész, Kinga, and Coplen, T.B, eds., Methods of the Reston Stable Isotope Laboratory: U.S. Geological Survey Techniques and Methods 10–C1, 27 p.

Révész, Kinga, and Coplen, T.B., 2008b, Determination of the $\delta(^{18}O/^{16}O)$ of water—RSIL lab code 489, chap. C2 *of* Révész, Kinga, and Coplen, T.B, eds., Methods of the Reston Stable Isotope Laboratory: U.S. Geological Survey Techniques and Methods 10–C2, 28 p.

Rothenberger, M.B., Burkholder, J.M., and Brownie, C., 2009, Long-term effects of changing land use practices on surface water quality in a coastal river and lagoonal estuary: Environmental Management, v. 44, p. 505–523.

Seitzinger, S., Harrison, J.A., Böhlke, J.K., Bouwman, A.F., Lowrance, R., Peterson, B., Tobias, C., and Van Drecht, G., 2006, Denitrification across landscapes and waterscapes—A synthesis: Ecological Applications, v. 16, no. 6, p. 2064–2090.

Sigman, D.M., Casciotti, K.L., Andreani, M., Barford, C., Galanter, M., and Böhlke, J.K., 2001, A bacterial method for the nitrogen isotopic analysis of seawater and freshwater: Analytical Chemistry, v. 73, p. 4145–4153.

Sims, J.T., Bergstörm, L., Bowman, B.T., and Oenema, O., 2005, Nutrient management for intensive animal agriculture—Policies and practices for sustainability: Soil Use and Management, v. 21, p. 141–151.

Smith, J.T., and Evan, R.O., 1998, Evaluation of BMPs to improve drainage water quality from agricultural land irrigated with swine lagoon effluent, *in* Brown, L.C., ed., Drainage in the 21st century—Food production and the environment: Proceedings of the 7th International Drainage Symposium, American Society of Agricultural Engineers, Orlando Fla., March 8–11, 1998, p. 9–16.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture [n.d.]: Web Soil Survey, accessed March 4, 2013, at http://websoilsurvey.nrcs.usda.gov/.

Speiran, G.K., Hamilton, P.A., and Woodside, M.D., 1998, Natural processes for managing nitrate in ground water discharged to Chesapeake Bay and other surface waters—More than forest buffers: U.S. Geological Survey Fact Sheet 178–97, 4 p.

Spruill, T.B., 2000, Statistical evaluation of effects of riparian buffers on nitrate and ground-water quality: Journal of Environmental Quality, v. 29, no. 5, p. 1523–1538.

Spruill, T.B., Harned, D.A., Ruhl, P.M., Eimers, J.L., McMahon, G., Smith, K.E., Galeone, D.R., and Woodside, M.D., 1998, Water quality in the Albemarle-Pamlico drainage basin, North Carolina and Virginia, 1992–95: U.S. Geological Survey Circular 1157, 36 p.

Spruill, T.B., Showers, W.J., and Howe, S.S., 2002, Application of classification-tree methods to identify nitrate sources in ground water: Journal of Environmental Quality, v. 31, no. 5, p. 1538–1549.

Spruill, T.B., Tesoriero, A.J., Mew, H.E., Jr., Farrell, K.M., Harden, S.L., Colosimo, A.G., and Kramer, S.R., 2005, Geochemistry and characteristics of nitrogen transport at a confined animal feeding operation in a Coastal Plain agricultural watershed, and implications for nutrient loading in the Neuse River basin, North Carolina, 1999–2002: U.S. Geological Survey Scientific Investigations Report 2004–5283, 57 p.

State Climate Office of North Carolina, [n.d], 1971–2000 Climate Normals: State Climate Office of North Carolina, North Carolina State University, accessed December 2, 2014, at http://www.nc-climate.ncsu.edu/cronos/normals.php?order=county.

Stone, K.C., Hunt, P.G., Coffey, S.W., and Matheny, T.A., 1995, Water quality status of a USDA water quality demonstration project in the Eastern Coastal Plain: Journal of Soil and Water Conservation, v. 50, no. 5, p. 567–571.

Stone, K.C., Hunt, P.G., Humenik, F.J., and Johnson, M.H., 1998, Impact of swine waste application on ground and stream water quality in an eastern coastal plain watershed: Transactions of the American Society of Agricultural Engineers, v. 41, no. 6, p. 1665–1670.

Stow, C.A., Borsuk, M.E., and Stanley, D.W., 2001, Long-term changes in watershed nutrient inputs and riverine exports in the Neuse River, North Carolina: Water Research, v. 35, p. 1489–1499.

Tesoriero, A.J., Liebscher, H., and Cox, S.E., 2000, Mechanism and rate of denitrification in an agricultural watershed—Electron and mass balance along groundwater flow paths: Water Resources Research, v. 36, no. 6, p. 1545–1559.

Tesoriero, A.J., Spruill, T.B., Mew, H.E., Jr., Farrell, K.M., and Harden, S.L., 2005, Nitrogen transport and transformation in a coastal plain watershed: Influence of geomorphology on flow paths and residence times: Water Resources Research, v. 41, 15 p., accessed May 11, 2015, at http://dx.doi.org/10.1029/2003WR002953.

Tucker, M.R., 1999, Essential plant nutrients—Their presence in North Carolina soils and role in plant nutrition: North Carolina Department of Agriculture and Consumer Services, Agronomic Services, accessed May 6, 2014, at http://www.ncagr.gov/agronomi/pubs.htm.

U.S. Department of Agriculture, Natural Resources Conservation Service, 2009, Chapter 7 Hydrologic Soil Groups: National Engineering Handbook, Part 630 Hydrology, accessed December 2, 2013, at http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/?cid=stelprdb1043063.

U.S. Environmental Protection Agency, 1993, Method 365.1 Determination of phosphorus by semi-automated colorimetry, Revision 2.0, Methods for the determination of inorganic substances in environmental samples: U.S. Environmental Protection Agency EPA/600/R-93/100.

U.S. Environmental Protection Agency, 2010, National Water Quality Inventory Report to Congress, Electronic integrated reporting under Sections 305(b) and 303(d), 2010 reporting year, accessed June 17, 2013, at http://water.epa.gov/lawsregs/guidance/cwa/305b/index.cfm.

U.S. Environmental Protection Agency, 2012, NPDES permit writers' manual for concentrated animal feeding operations, EPA 833-F-12-001, accessed April 10, 2015, at http://water.epa.gov/polwaste/npdes/afo/Implementation-Information.cfm.

U.S. Geological Survey, 2006, Collection, quality assurance, and presentation of precipitation data: U.S. Geological Survey, Office of Surface Water Technical Memorandum No. 2006.01 (revised December 2009), 29 p., accessed August 5, 2014, at http://water.usgs.gov/admin/memo/SW/sw06.012_Revised_122009.pdf.

U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1–A9, available online at http://pubs.water.usgs.gov/twri9A.

Weaver, J.C., Terziotti, Silvia, Kolb, K.R., and Wagner, C.R., 2012, StreamStats in North Carolina—A water-resources Web application: U.S. Geological Survey Fact Sheet 2012–3137, 4 p.

Xue, D., Botte, J., De Baets, B., Accoe, F., Nestler, A., Taylor, P., Van Cleemput, O., Berglund, M., and Boeckx, P., 2009, Present limitations and future prospects of stable isotope methods for nitrate source identification in surface- and groundwater: Water Research, v. 43, p. 1159–1170.

Zublena, J.P., Baird, J.V., and Lilly, J.P., 1991, SoilFacts—Nutrient content of fertilizer and organic materials: North Carolina Cooperative Extension Service Publication AG-439-18, accessed May 5, 2014, at http://www.soil.ncsu.edu/publications/extension.html.

Zublena, J.P., Barker, J.C., and Carter, T.A., 1997b, SoilFacts—Poultry manure as a fertilizer source: North Carolina Cooperative Extension Service Publication AG-439-5, accessed May 5, 2014, at http://www.soil.ncsu.edu/publications/extension.html.

Zublena, J.P., Barker, J.C., Parker, J.W., and Stanislaw, C.M., 1997a, SoilFacts—Swine manure as a fertilizer source: North Carolina Cooperative Extension Service Publication AG-439-4, accessed May 5, 2014, at http://www.soil.ncsu.edu/publications/extension.html.

Manuscript was approved on June 4, 2015

For further information about this publication contact:

Director
U.S. Geological Survey
South Atlantic Water Science Center
720 Gracern Road
Columbia, SC 29210
http://www.usgs.gov/water/southatlantic/

Prepared by the Raleigh Publishing Service Center

Harden—**Surface-Water Quality at Agricultural Watersheds of the North Carolina Coastal Plain Associated with CAFOs**—Scientific Investigations Report 2015–5080

ISSN 2326-0328 (online)
http://dx.doi.org/10.3133/sir20155080

EXHIBIT N

Sun Journal
NEW BERN, NORTH CAROLINA

Print Page

By Travis Graves

September 12. 2015 6:29PM

Commentary: What happens there, doesn't stay there

The majority of folks in the coastal plain aren't aware of the proposal by Sanderson Farms to build a chicken slaughterhouse in the small town of St. Pauls, nor are they aware of what this will mean for the waters of the Lower Neuse basin.

On Sept. 17, the N.C. Department of Environment and Natural Resources will be holding a public hearing regarding the proposed slaughterhouse at the R. E. Hooks Community Building at 7 p.m. in St. Pauls and here's why you should go and have your voice heard for the sake of our beloved waters:

The slaughterhouse proposed to be located in St. Pauls is virtually identical to a Sanderson Farms factory located in Kinston, and the stories of the two facilities are shaping up to be uncomfortably similar in their reliance on backroom deals and an uninformed public. After an initial uproar of opposition to the slaughterhouse proposal the project was seemingly abandoned with no public information provided for over a year. Only after secret negotiations between the company and Kinston officials was it announced publicly that they had struck a deal and construction moved forward.

The new St. Pauls plant was originally slated to be located in Nash County under the auspicious code name "Project Baseball," but, after vocal opposition from local residents, the project was abandoned. Then last year, "Project Destiny" was sprung on residents in Cumberland County. Again, strong local opposition ultimately ran the proposed slaughterhouse out of town. Now, the project has quietly resurfaced in Robeson County with little to no public involvement.

If questionable government and corporate dealings aren't enough to raise a few eyebrows, the environmental impacts of the proposed facility should be. In order to supply the chickens for a new slaughterhouse capable of butchering 1.25 million birds per week, hundreds of new confinement houses will need to be constructed, houses that would produce roughly 2.5 million pounds of bacteria, arsenic, and pathogen laden animal waste per week. The logistics of feeding that many birds is no small feat, so the confinement houses will be built as close to their feed source as possible, and they'll be supplied with feed from a mill located at the Kinston plant, right in the heart of the Neuse River basin.

Nutrient pollution in the Neuse, in large part from industrial animal operations, is silently killing our river. Over the past 30 years, since industrial meat production moved into the coastal plain, we've suffered massive fish kills directly related to algae blooms which deplete oxygen and suffocate fish. The latest of these occurred earlier this summer as our children played along beaches covered in rotting menhaden.

There are also pathogens and fecal bacteria like E. coli flowing downstream after rain and wind transports feces that has been improperly stored and spread on fields across the watershed. I've documented and reported fifteen violations of poultry waste storage regulations to DENR this year alone, and they haven't once enforced the law. I can't even find out if my complaints are being investigated because the N.C. legislature passed a law last year making complaints confidential, even keeping this information from the person submitting the complaint. When industry and regulators are allowed to operate behind a curtain, don't expect them to act in anyone's interest but their own, and all private corporations have one singular interest: maximizing profits.

Here in New Bern we wouldn't have to suffer the burden of the factory, or the constant traffic of open-air chicken trucks spreading odor, feathers, and feces across town, but we will bear the impacts of polluted water incapable of supporting all the life depending on it. The Neuse is at its breaking point, and we cannot stand idly by. I'll be at the public hearing in St. Pauls, and I hope you'll join me to voice your concerns for our river, and support for the communities that depend upon it remaining fishable, swimmable and drinkable for generations to come.

Travis Graves is the Lower Neuse Riverkeeper and lives in New Bern.

http://www.newbernsj.com/article/20150912/OPINION/150919594

Print Page

EXHIBIT O

Kemp Burdette: Don't play chicken with river

By Kemp Burdette
For StarNews Media
Published: Wednesday, September 16, 2015 at 8:50 a.m.

Last year, I stood with community members in Cumberland County to fend off the proposed construction of a Sanderson Farms chicken slaughterhouse in their community. Despite backroom deals and secret meetings between corporate executives and government officials, we were able to make our voices heard and defeat "Project Destiny." Now, Sanderson Farms is back, and even though they've moved to the small town of St. Pauls in Robeson County, construction of this slaughterhouse would still be a death sentence to water quality in the Cape Fear – the source of so much drinking water in southeastern North Carolina.

On September 17th, the NC Department of Environment and Natural Resources (DENR) will be holding a public hearing over the proposed slaughterhouse at the R. E. Hooks Community Building at 7:00 PM in St. Pauls, NC, and here's why you should go and have your voice heard:

In order to supply a new slaughterhouse capable of butchering 1.25 million chickens per week, hundreds of new confinement buildings will need to be constructed, producing roughly 2.5 million pounds of bacteria, arsenic, and nutrient laden waste per week. They'll be supplied with feed from an existing mill located in Kinston, NC. To save the company money on transportation costs, the ideal location for all of these new chicken-growing operations is right here in the Cape Fear Basin.

Nutrient pollution in the Cape Fear, in large part from industrial animal operations, is a huge issue and one the industry has worked hard to keep quiet. In recent years, including this one, toxic algae blooms have appeared just above Lock and Dam #1 at the drinking water intakes for about a half million people in New Hanover and Brunswick Counties, including the City of Wilmington. This is the same problem that caused the City of Toledo, Ohio to cut off the drinking water supply to its citizens for three days last year due to the high levels of toxicmicrocystis algae.

Additionally, pathogens and fecal bacteria like e. coli flowdownstream after they are washed or blown into waterways from improper storage and land application. I've documented and reported ten violations of poultry waste storage regulations to DENR so far this year, and they haven't once enforced the law. I can't even find out if my complaints were investigated because the NC legislature passed a law last year making complaints confidential, even making information secret to the person submitting the complaint! When an industry and regulators can operate behind a curtain, don't expect them to act in anyone's interest but their own.

While we won't be burdened with the slaughterhouse operationsand constant traffic of open-air chicken trucks, spreading odor, feathers, and feces across town, we will bear the downstream impacts of polluted and toxic water. And of course this isn't happening in a vacuum. Right now, while Sanderson Farms is trying to add enormous amounts of waste to our river, other polluters have petitioned DENR (which appears to be more than willing to do industry's bidding at the expense of the environment and public health these days) to lower the water quality designation of the Lower Cape Fear so they can pollute our river even more. In a region that prides and sustains itself on its riverfront and beaches, we can't allow this to happen sitting down. I'll be at the public hearing in St. Pauls, and I hope you'll join me for the future of our river.

Kemp Burdette is Cape Fear Riverkeeper and director of Cape Fear River Watch.

EXHIBIT P

Christine Ellis: How will Sanderson Farms affect St. Pauls?

By Christine Ellis | Posted: Sunday, September 13, 2015 12:00 am

So far, no environmental study has been conducted to evaluate the impacts of the Sanderson Farms chicken slaughterhouse proposed to be located near St. Pauls in Robeson County. Wouldn't you want to know what effect the project could have on you, your family and your quality of life? I certainly do.

Only one small part of the project will be discussed at a public hearing Thursday at 7 p.m. at the R.E. Hooks Community Building at 176 N. Third St. in St. Pauls. This hearing may be the only opportunity for the public to learn how Sanderson will treat and dispose of wastewater from the proposed processing plant.

I will be there and encourage anyone who values clean water and healthy communities to join me.

Information about this project has been hard to come by, since most of the negotiations and decision-making have taken place in secret. This is especially true regarding impacts on the community and the environment. There is no evidence that the town of St. Pauls or Robeson County even considered how the slaughterhouse might affect the environment or public health.

I don't understand why this important analysis has been ignored. It could have been done prior to any decisions being made to site the slaughterhouse near St. Pauls, to predict environmental impacts at an early stage in project planning and design. It could have been used to shape the project to suit the local environment. It could have been used to ensure that the project meets the needs of the community.

But neither the county nor the town has conducted any type of environmental impacts analysis, and therefore they cannot ensure that Sanderson will protect the natural resources of Robeson County.

Poultry processing causes pollution, and most of Sanderson Farms' seven slaughterhouses have been cited for illegal discharges to public waters. For example, the Bryan, Texas, plant has illegally polluted public waters with fecal bacteria for the past three years. Other plants in Texas, Louisiana and Mississippi also are causing water pollution, and they all have more stringent requirements than the company's slaughterhouse in Kinston and the proposed St. Pauls plant. (Source: EPA Enforcement and Compliance History Online database at echo.epa.gov.)

In Kinston, a "nondischarge" permit allows Sanderson Farms to spray wastewater onto nearby land. That permit doesn't require the same level of treatment as the plants mentioned above. There are no limits for bacteria, nutrients and other pollutants discharged to land. Although groundwater monitoring at the Kinston plant only occurs three times a year, the results of well sampling show groundwater contamination. Inexplicably, no monitoring of nearby public waters is required, despite reports of runoff into nearby waterways.

A comprehensive study will identify the potential for environmental impacts. It will help to ensure that any negative impacts are mitigated. Without this analysis, how can the community be assured that clean water will be protected, that local families won't suffer health consequences, and that the community won't bear the burden of a reduced quality of life?

Our government officials need to make sure proper standards are in place to prevent pollution. In addition, Sanderson Farms must be held accountable for any negative impacts to St. Pauls and the surrounding area. A comprehensive environmental impact study of the proposed processing plant is needed. The community deserves to know the environmental consequences of Sanderson Farms' operation and needs assurances that it won't be negatively impacted. Working together we can make a difference to protect clean water and healthy communities for our children and ourselves.

Christine Ellis is the river advocate for the environmental nonprofit Winyah Rivers Foundation, which advocates for clean water protections and fishable, swimmable and drinkable water.

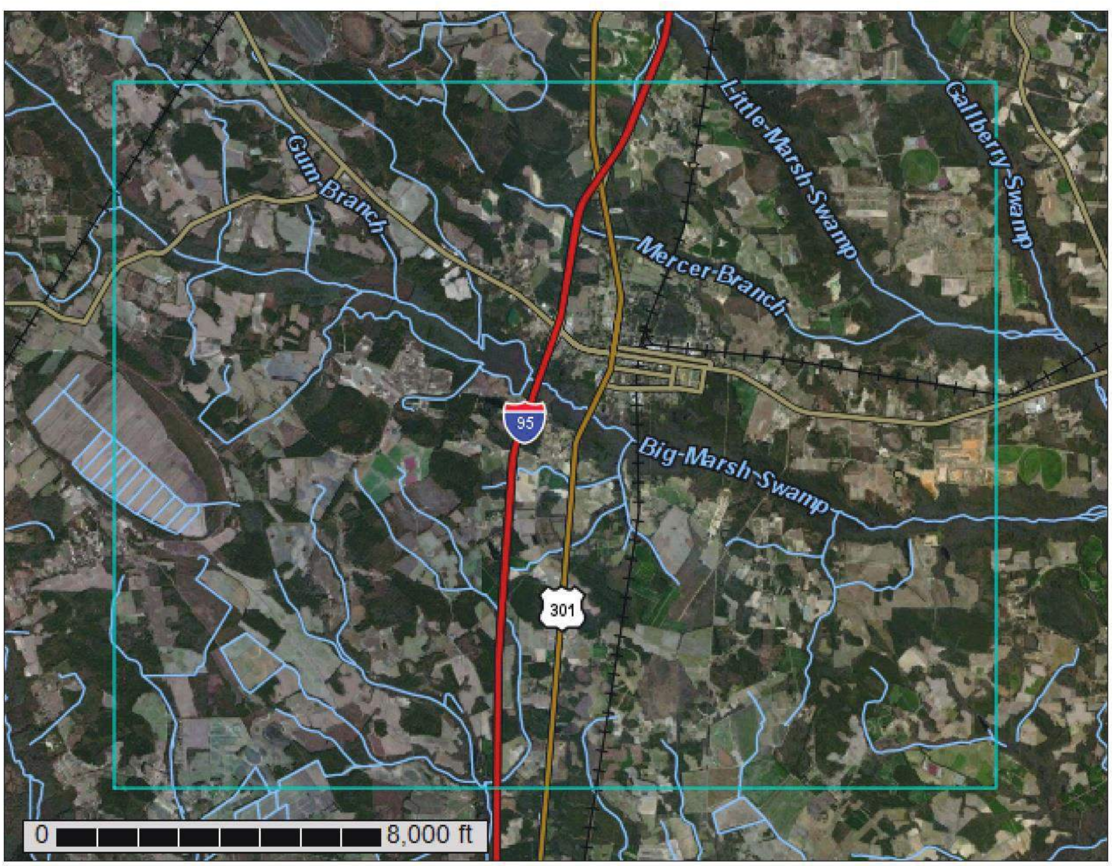
EXHIBIT Q

USDA United States Department of Agriculture

NRCS Natural Resources Conservation Service

A product of the National Cooperative Soil Survey, a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local participants

Custom Soil Resource Report for Cumberland County, North Carolina, and Robeson County, North Carolina



May 28, 2015

Preface

Soil surveys contain information that affects land use planning in survey areas. They highlight soil limitations that affect various land uses and provide information about the properties of the soils in the survey areas. Soil surveys are designed for many different users, including farmers, ranchers, foresters, agronomists, urban planners, community officials, engineers, developers, builders, and home buyers. Also, conservationists, teachers, students, and specialists in recreation, waste disposal, and pollution control can use the surveys to help them understand, protect, or enhance the environment.

Various land use regulations of Federal, State, and local governments may impose special restrictions on land use or land treatment. Soil surveys identify soil properties that are used in making various land use or land treatment decisions. The information is intended to help the land users identify and reduce the effects of soil limitations on various land uses. The landowner or user is responsible for identifying and complying with existing laws and regulations.

Although soil survey information can be used for general farm, local, and wider area planning, onsite investigation is needed to supplement this information in some cases. Examples include soil quality assessments (http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/) and certain conservation and engineering applications. For more detailed information, contact your local USDA Service Center (http://offices.sc.egov.usda.gov/locator/app?agency=nrcs) or your NRCS State Soil Scientist (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/contactus/?cid=nrcs142p2_053951).

Great differences in soil properties can occur within short distances. Some soils are seasonally wet or subject to flooding. Some are too unstable to be used as a foundation for buildings or roads. Clayey or wet soils are poorly suited to use as septic tank absorption fields. A high water table makes a soil poorly suited to basements or underground installations.

The National Cooperative Soil Survey is a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local agencies. The Natural Resources Conservation Service (NRCS) has leadership for the Federal part of the National Cooperative Soil Survey.

Information about soils is updated periodically. Updated information is available through the NRCS Web Soil Survey, the site for official soil survey information.

The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or a part of an individual's income is derived from any public assistance program. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD). To file a complaint of discrimination, write to USDA, Director, Office of Civil Rights, 1400 Independence Avenue, S.W., Washington, D.C. 20250-9410 or call (800) 795-3272 (voice) or (202) 720-6382 (TDD). USDA is an equal opportunity provider and employer.

Contents

How Soil Surveys Are Made

Soil surveys are made to provide information about the soils and miscellaneous areas in a specific area. They include a description of the soils and miscellaneous areas and their location on the landscape and tables that show soil properties and limitations affecting various uses. Soil scientists observed the steepness, length, and shape of the slopes; the general pattern of drainage; the kinds of crops and native plants; and the kinds of bedrock. They observed and described many soil profiles. A soil profile is the sequence of natural layers, or horizons, in a soil. The profile extends from the surface down into the unconsolidated material in which the soil formed or from the surface down to bedrock. The unconsolidated material is devoid of roots and other living organisms and has not been changed by other biological activity.

Currently, soils are mapped according to the boundaries of major land resource areas (MLRAs). MLRAs are geographically associated land resource units that share common characteristics related to physiography, geology, climate, water resources, soils, biological resources, and land uses (USDA, 2006). Soil survey areas typically consist of parts of one or more MLRA.

The soils and miscellaneous areas in a survey area occur in an orderly pattern that is related to the geology, landforms, relief, climate, and natural vegetation of the area. Each kind of soil and miscellaneous area is associated with a particular kind of landform or with a segment of the landform. By observing the soils and miscellaneous areas in the survey area and relating their position to specific segments of the landform, a soil scientist develops a concept, or model, of how they were formed. Thus, during mapping, this model enables the soil scientist to predict with a considerable degree of accuracy the kind of soil or miscellaneous area at a specific location on the landscape.

Commonly, individual soils on the landscape merge into one another as their characteristics gradually change. To construct an accurate soil map, however, soil scientists must determine the boundaries between the soils. They can observe only a limited number of soil profiles. Nevertheless, these observations, supplemented by an understanding of the soil-vegetation-landscape relationship, are sufficient to verify predictions of the kinds of soil in an area and to determine the boundaries.

Soil scientists recorded the characteristics of the soil profiles that they studied. They noted soil color, texture, size and shape of soil aggregates, kind and amount of rock fragments, distribution of plant roots, reaction, and other features that enable them to identify soils. After describing the soils in the survey area and determining their properties, the soil scientists assigned the soils to taxonomic classes (units). Taxonomic classes are concepts. Each taxonomic class has a set of soil characteristics with precisely defined limits. The classes are used as a basis for comparison to classify soils systematically. Soil taxonomy, the system of taxonomic classification used in the United States, is based mainly on the kind and character of soil properties and the arrangement of horizons within the profile. After the soil scientists classified and named the soils in the survey area, they compared the individual soils with similar soils in the same taxonomic class in other areas so that they could confirm data and assemble additional data based on experience and research.

The objective of soil mapping is not to delineate pure map unit components; the objective is to separate the landscape into landforms or landform segments that have similar use and management requirements. Each map unit is defined by a unique combination of soil components and/or miscellaneous areas in predictable proportions. Some components may be highly contrasting to the other components of the map unit. The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The delineation of such landforms and landform segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, onsite investigation is needed to define and locate the soils and miscellaneous areas.

Soil scientists make many field observations in the process of producing a soil map. The frequency of observation is dependent upon several factors, including scale of mapping, intensity of mapping, design of map units, complexity of the landscape, and experience of the soil scientist. Observations are made to test and refine the soil-landscape model and predictions and to verify the classification of the soils at specific locations. Once the soil-landscape model is refined, a significantly smaller number of measurements of individual soil properties are made and recorded. These measurements may include field measurements, such as those for color, depth to bedrock, and texture, and laboratory measurements, such as those for content of sand, silt, clay, salt, and other components. Properties of each soil typically vary from one point to another across the landscape.

Observations for map unit components are aggregated to develop ranges of characteristics for the components. The aggregated values are presented. Direct measurements do not exist for every property presented for every map unit component. Values for some properties are estimated from combinations of other properties.

While a soil survey is in progress, samples of some of the soils in the area generally are collected for laboratory analyses and for engineering tests. Soil scientists interpret the data from these analyses and tests as well as the field-observed characteristics and the soil properties to determine the expected behavior of the soils under different uses. Interpretations for all of the soils are field tested through observation of the soils in different uses and under different levels of management. Some interpretations are modified to fit local conditions, and some new interpretations are developed to meet local needs. Data are assembled from other sources, such as research information, production records, and field experience of specialists. For example, data on crop yields under defined levels of management are assembled from farm records and from field or plot experiments on the same kinds of soil.

Predictions about soil behavior are based not only on soil properties but also on such variables as climate and biological activity. Soil conditions are predictable over long periods of time, but they are not predictable from year to year. For example, soil scientists can predict with a fairly high degree of accuracy that a given soil will have a high water table within certain depths in most years, but they cannot predict that a high water table will always be at a specific level in the soil on a specific date.

After soil scientists located and identified the significant natural bodies of soil in the survey area, they drew the boundaries of these bodies on aerial photographs and identified each as a specific map unit. Aerial photographs show trees, buildings, fields, roads, and rivers, all of which help in locating boundaries accurately.

Soil Map

The soil map section includes the soil map for the defined area of interest, a list of soil map units on the map and extent of each map unit, and cartographic symbols displayed on the map. Also presented are various metadata about data used to produce the map, and a description of each soil map unit.

Custom Soil Resource Report
Soil Map

MAP LEGEND

Area of Interest (AOI)
- Area of Interest (AOI)

Soils
- Soil Map Unit Polygons
- Soil Map Unit Lines
- Soil Map Unit Points

Special Point Features
- Blowout
- Borrow Pit
- Clay Spot
- Closed Depression
- Gravel Pit
- Gravelly Spot
- Landfill
- Lava Flow
- Marsh or swamp
- Mine or Quarry
- Miscellaneous Water
- Perennial Water
- Rock Outcrop
- Saline Spot
- Sandy Spot
- Severely Eroded Spot
- Sinkhole
- Slide or Slip
- Sodic Spot
- Spoil Area
- Stony Spot
- Very Stony Spot
- Wet Spot
- Other
- Special Line Features

Water Features
- Streams and Canals

Transportation
- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background
- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at scales ranging from 1:20,000 to 1:24,000.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Cumberland County, North Carolina
Survey Area Data: Version 14, Sep 12, 2014

Soil Survey Area: Robeson County, North Carolina
Survey Area Data: Version 12, Sep 12, 2014

Your area of interest (AOI) includes more than one soil survey area. These survey areas may have been mapped at different scales, with a different land use in mind, at different times, or at different levels of detail. This may result in map unit symbols, soil properties, and interpretations that do not completely agree across soil survey area boundaries.

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Mar 7, 2010—Apr 3, 2011

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

Cumberland County, North Carolina (NC051)			
Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
AuA	Autryville loamy sand, 0 to 2 percent slopes	6.4	0.0%
CaB	Candor sand, 1 to 8 percent slopes	19.3	0.0%
GoA	Goldsboro loamy sand, 0 to 2 percent slopes	1.1	0.0%
JT	Johnston loam	71.5	0.2%
Pa	Pactolus loamy sand	1.6	0.0%
WaB	Wagram loamy sand, 0 to 6 percent slopes	3.9	0.0%
Subtotals for Soil Survey Area		**103.9**	**0.2%**
Totals for Area of Interest		**42,735.8**	**100.0%**

Robeson County, North Carolina (NC155)			
Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
BB	Bibb soils	679.5	1.6%
Bp	Borrow pit	114.5	0.3%
By	Byars loam	1,359.7	3.2%
Co	Coxville loam	5,450.9	12.8%
Dn	Dunbar sandy loam	416.4	1.0%
DpA	Duplin sandy loam, 0 to 2 percent slopes	279.7	0.7%
DpB	Duplin sandy loam, 2 to 6 percent slopes	6.9	0.0%
FaB	Faceville fine sandy loam, 2 to 6 percent slopes	15.9	0.0%
GoA	Goldsboro loamy sand, 0 to 2 percent slopes	3,208.0	7.5%
Jo	Johns sandy loam	93.4	0.2%
JT	Johnston soils	4,866.8	11.4%
KaA	Kalmia loamy sand, 0 to 2 percent slopes	7.8	0.0%
LaB	Lakeland sand, 0 to 6 percent slopes	1,203.1	2.8%
Le	Leon sand	299.6	0.7%
Lu	Lumbee sandy loam	20.1	0.0%
Ly	Lynchburg sandy loam	1,854.0	4.3%
MaA	Marlboro sandy loam, 0 to 2 percent slopes	71.9	0.2%

Robeson County, North Carolina (NC155)			
Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
MaB	Marlboro sandy loam, 2 to 6 percent slopes	25.5	0.1%
Mc	McColl loam	1,132.4	2.6%
NoA	Norfolk loamy sand, 0 to 2 percent slopes	6,518.7	15.3%
NoB	Norfolk loamy sand, 2 to 6 percent slopes	258.1	0.6%
NsC	Norfolk and Faceville soils, 6 to 10 percent slopes	39.1	0.1%
Pa	Pactolus loamy sand	126.7	0.3%
Pg	Pantego fine sandy loam	890.5	2.1%
Pm	Plummer and Osier soils	174.3	0.4%
PoB	Pocalla loamy sand, 0 to 3 percent slopes	708.9	1.7%
Pr	Ponzer muck, siliceous subsoil variant (Croatan)	96.6	0.2%
Pt	Portsmouth loam	42.7	0.1%
Ra	Rains sandy loam	4,581.9	10.7%
Ru	Rutlege loamy sand	117.8	0.3%
Ta	Toisnot loam	264.2	0.6%
To	Torhunta loam	39.5	0.1%
Ud	Udorthents, loamy	95.7	0.2%
W	Water	100.9	0.2%
WaB	Wagram loamy sand, 0 to 6 percent slopes	5,382.2	12.6%
WaC	Wagram loamy sand, 6 to 10 percent slopes	69.6	0.2%
WkB	Wakulla sand, 0 to 6 percent slopes	2,018.5	4.7%
Subtotals for Soil Survey Area		**42,632.0**	**99.8%**
Totals for Area of Interest		**42,735.8**	**100.0%**

Map Unit Descriptions

The map units delineated on the detailed soil maps in a soil survey represent the soils or miscellaneous areas in the survey area. The map unit descriptions, along with the maps, can be used to determine the composition and properties of a unit.

A map unit delineation on a soil map represents an area dominated by one or more major kinds of soil or miscellaneous areas. A map unit is identified and named according to the taxonomic classification of the dominant soils. Within a taxonomic class there are precisely defined limits for the properties of the soils. On the landscape, however, the soils are natural phenomena, and they have the characteristic variability of all natural phenomena. Thus, the range of some observed properties may extend beyond the limits defined for a taxonomic class. Areas of soils of a single taxonomic class rarely, if ever, can be mapped without including areas of other taxonomic classes. Consequently, every map unit is made up of the soils or miscellaneous areas for which it is named and some minor components that belong to taxonomic classes other than those of the major soils.

Most minor soils have properties similar to those of the dominant soil or soils in the map unit, and thus they do not affect use and management. These are called noncontrasting, or similar, components. They may or may not be mentioned in a particular map unit description. Other minor components, however, have properties and behavioral characteristics divergent enough to affect use or to require different management. These are called contrasting, or dissimilar, components. They generally are in small areas and could not be mapped separately because of the scale used. Some small areas of strongly contrasting soils or miscellaneous areas are identified by a special symbol on the maps. If included in the database for a given area, the contrasting minor components are identified in the map unit descriptions along with some characteristics of each. A few areas of minor components may not have been observed, and consequently they are not mentioned in the descriptions, especially where the pattern was so complex that it was impractical to make enough observations to identify all the soils and miscellaneous areas on the landscape.

The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The objective of mapping is not to delineate pure taxonomic classes but rather to separate the landscape into landforms or landform segments that have similar use and management requirements. The delineation of such segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, however, onsite investigation is needed to define and locate the soils and miscellaneous areas.

An identifying symbol precedes the map unit name in the map unit descriptions. Each description includes general facts about the unit and gives important soil properties and qualities.

Soils that have profiles that are almost alike make up a *soil series*. Except for differences in texture of the surface layer, all the soils of a series have major horizons that are similar in composition, thickness, and arrangement.

Soils of one series can differ in texture of the surface layer, slope, stoniness, salinity, degree of erosion, and other characteristics that affect their use. On the basis of such differences, a soil series is divided into *soil phases*. Most of the areas shown on the detailed soil maps are phases of soil series. The name of a soil phase commonly indicates a feature that affects use or management. For example, Alpha silt loam, 0 to 2 percent slopes, is a phase of the Alpha series.

Some map units are made up of two or more major soils or miscellaneous areas. These map units are complexes, associations, or undifferentiated groups.

A *complex* consists of two or more soils or miscellaneous areas in such an intricate pattern or in such small areas that they cannot be shown separately on the maps. The pattern and proportion of the soils or miscellaneous areas are somewhat similar in all areas. Alpha-Beta complex, 0 to 6 percent slopes, is an example.

An *association* is made up of two or more geographically associated soils or miscellaneous areas that are shown as one unit on the maps. Because of present or anticipated uses of the map units in the survey area, it was not considered practical or necessary to map the soils or miscellaneous areas separately. The pattern and relative proportion of the soils or miscellaneous areas are somewhat similar. Alpha-Beta association, 0 to 2 percent slopes, is an example.

An *undifferentiated group* is made up of two or more soils or miscellaneous areas that could be mapped individually but are mapped as one unit because similar interpretations can be made for use and management. The pattern and proportion of the soils or miscellaneous areas in a mapped area are not uniform. An area can be made up of only one of the major soils or miscellaneous areas, or it can be made up of all of them. Alpha and Beta soils, 0 to 2 percent slopes, is an example.

Some surveys include *miscellaneous areas*. Such areas have little or no soil material and support little or no vegetation. Rock outcrop is an example.

Cumberland County, North Carolina

AuA—Autryville loamy sand, 0 to 2 percent slopes

Map Unit Setting

National map unit symbol: w6yt
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Autryville and similar soils: 90 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Autryville

Setting

Landform: Flats on marine terraces, ridges on marine terraces
Landform position (two-dimensional): Shoulder, summit
Landform position (three-dimensional): Crest
Down-slope shape: Convex
Across-slope shape: Convex
Parent material: Sandy and loamy marine deposits

Typical profile

Ap - 0 to 9 inches: loamy sand
E and B - 9 to 26 inches: loamy sand
Bt - 26 to 46 inches: sandy loam
E' - 46 to 58 inches: loamy sand
B't - 58 to 85 inches: sandy clay loam

Properties and qualities

Slope: 0 to 6 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Well drained
Runoff class: Very low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 48 to 72 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Low (about 5.0 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2s
Hydrologic Soil Group: A

CaB—Candor sand, 1 to 8 percent slopes

Map Unit Setting

National map unit symbol: w6zj
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Not prime farmland

Map Unit Composition

Candor and similar soils: 80 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Candor

Setting

Landform: Ridges on marine terraces
Landform position (two-dimensional): Shoulder, summit
Landform position (three-dimensional): Crest
Down-slope shape: Convex
Across-slope shape: Convex
Parent material: Sandy and loamy marine deposits and/or eolian sands

Typical profile

A - 0 to 8 inches: sand
E - 8 to 26 inches: sand
Bt - 26 to 38 inches: loamy sand
E' - 38 to 62 inches: sand
B't - 62 to 80 inches: sandy clay loam

Properties and qualities

Slope: 1 to 8 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Somewhat excessively drained
Runoff class: Low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Very low (about 2.9 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4s
Hydrologic Soil Group: A

GoA—Goldsboro loamy sand, 0 to 2 percent slopes

Map Unit Setting

National map unit symbol: w70n
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: All areas are prime farmland

Map Unit Composition

Goldsboro and similar soils: 90 percent
Minor components: 5 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Goldsboro

Setting

Landform: Flats on marine terraces, broad interstream divides on marine terraces
Landform position (two-dimensional): Summit
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Loamy marine deposits

Typical profile

Ap - 0 to 8 inches: loamy sand
E - 8 to 15 inches: loamy sand
Bt - 15 to 45 inches: sandy clay loam
Btg - 45 to 80 inches: sandy clay loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Moderately well drained
Runoff class: Low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 24 to 36 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Moderate (about 8.0 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2w
Hydrologic Soil Group: B

Minor Components

Rains, undrained

Percent of map unit: 5 percent

Landform: Flats on marine terraces, carolina bays on marine terraces, broad interstream divides on marine terraces
Landform position (two-dimensional): Summit
Down-slope shape: Linear
Across-slope shape: Linear

JT—Johnston loam

Map Unit Setting

National map unit symbol: w70r
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Not prime farmland

Map Unit Composition

Johnston, undrained, and similar soils: 85 percent
Johnston, drained, and similar soils: 15 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Johnston, Undrained

Setting

Landform: Flood plains
Down-slope shape: Concave
Across-slope shape: Linear
Parent material: Sandy and loamy alluvium

Typical profile

A - 0 to 30 inches: mucky loam
Cg1 - 30 to 34 inches: loamy fine sand
Cg2 - 34 to 80 inches: fine sandy loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Very poorly drained
Runoff class: Ponded
Capacity of the most limiting layer to transmit water (Ksat): High (1.98 to 5.95 in/hr)
Depth to water table: About 0 inches
Frequency of flooding: Frequent
Frequency of ponding: Frequent
Available water storage in profile: High (about 9.4 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 7w
Hydrologic Soil Group: A/D

Description of Johnston, Drained

Setting

Landform: Flood plains
Down-slope shape: Concave
Across-slope shape: Linear
Parent material: Sandy and loamy alluvium

Typical profile

A - 0 to 30 inches: mucky loam
Cg1 - 30 to 34 inches: loamy fine sand
Cg2 - 34 to 80 inches: fine sandy loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Very poorly drained
Runoff class: Ponded
Capacity of the most limiting layer to transmit water (Ksat): High (1.98 to 5.95 in/hr)
Depth to water table: About 0 inches
Frequency of flooding: Frequent
Frequency of ponding: Frequent
Available water storage in profile: High (about 9.4 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4w
Hydrologic Soil Group: A/D

Pa—Pactolus loamy sand

Map Unit Setting

National map unit symbol: w71n
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Not prime farmland

Map Unit Composition

Pactolus and similar soils: 90 percent
Minor components: 5 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Pactolus

Setting

Landform: Ridges on stream terraces, ridges on marine terraces
Landform position (three-dimensional): Tread
Down-slope shape: Convex, concave

Across-slope shape: Convex, linear
Parent material: Sandy fluviomarine deposits and/or eolian sands

Typical profile

Ap - 0 to 8 inches: loamy sand
C - 8 to 40 inches: loamy sand
Cg - 40 to 80 inches: loamy sand

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Moderately well drained
Runoff class: Very low
Capacity of the most limiting layer to transmit water (Ksat): High to very high (5.95 to 19.98 in/hr)
Depth to water table: About 18 to 36 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Low (about 4.2 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3s
Hydrologic Soil Group: A

Minor Components

Lumbee, undrained

Percent of map unit: 5 percent
Landform: Backswamps on stream terraces
Down-slope shape: Concave
Across-slope shape: Linear

WaB—Wagram loamy sand, 0 to 6 percent slopes

Map Unit Setting

National map unit symbol: w72m
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Wagram and similar soils: 90 percent
Minor components: 5 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Wagram

Setting

Landform: Broad interstream divides on marine terraces, ridges on marine terraces
Landform position (two-dimensional): Shoulder, summit
Landform position (three-dimensional): Crest
Down-slope shape: Convex
Across-slope shape: Convex
Parent material: Loamy marine deposits

Typical profile

Ap - 0 to 8 inches: loamy sand
E - 8 to 24 inches: loamy sand
Bt - 24 to 75 inches: sandy clay loam
BC - 75 to 83 inches: sandy loam

Properties and qualities

Slope: 0 to 6 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Well drained
Runoff class: Low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 60 to 80 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Moderate (about 6.7 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2s
Hydrologic Soil Group: A

Minor Components

Bibb, undrained

Percent of map unit: 3 percent
Landform: Flood plains
Landform position (two-dimensional): Toeslope
Down-slope shape: Concave
Across-slope shape: Linear

Johnston, undrained

Percent of map unit: 2 percent
Landform: Flood plains
Down-slope shape: Concave
Across-slope shape: Linear

Robeson County, North Carolina

BB—Bibb soils

Map Unit Setting

National map unit symbol: 3vdw
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Not prime farmland

Map Unit Composition

Bibb, undrained, and similar soils: 80 percent
Johnston, undrained, and similar soils: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Bibb, Undrained

Setting

Landform: Flood plains
Landform position (two-dimensional): Toeslope
Down-slope shape: Concave
Across-slope shape: Linear
Parent material: Sandy and loamy alluvium

Typical profile

A - 0 to 6 inches: sandy loam
Cg1 - 6 to 60 inches: sandy loam
Cg2 - 60 to 80 inches: loamy sand

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Poorly drained
Runoff class: Low
Capacity of the most limiting layer to transmit water (Ksat): High (1.98 to 5.95 in/hr)
Depth to water table: About 0 to 12 inches
Frequency of flooding: Frequent
Frequency of ponding: None
Available water storage in profile: Moderate (about 7.2 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 5w
Hydrologic Soil Group: A/D

Description of Johnston, Undrained

Setting

Landform: Flood plains
Down-slope shape: Concave
Across-slope shape: Linear
Parent material: Sandy and loamy alluvium

Typical profile

A - 0 to 30 inches: mucky loam
Cg1 - 30 to 34 inches: loamy fine sand
Cg2 - 34 to 80 inches: fine sandy loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Very poorly drained
Runoff class: Ponded
Capacity of the most limiting layer to transmit water (Ksat): High (1.98 to 5.95 in/hr)
Depth to water table: About 0 inches
Frequency of flooding: Frequent
Frequency of ponding: Frequent
Available water storage in profile: High (about 9.4 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 7w
Hydrologic Soil Group: A/D

Bp—Borrow pit

Map Unit Setting

National map unit symbol: 1vykp
Elevation: 20 to 160 feet
Mean annual precipitation: 40 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 200 to 280 days
Farmland classification: Not prime farmland

Map Unit Composition

Pits, sand: 100 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Pits, Sand

Setting

Parent material: Sandy fluviomarine deposits

Typical profile

C1 - 0 to 10 inches: sand
C2 - 10 to 80 inches: sand

Properties and qualities

Slope: 0 to 3 percent
Runoff class: Very low
Capacity of the most limiting layer to transmit water (Ksat): High to very high (5.95 to 39.96 in/hr)
Depth to water table: About 0 to 6 inches
Available water storage in profile: Very low (about 2.4 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 8s

By—Byars loam

Map Unit Setting

National map unit symbol: 3vdx
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Byars, ponded, and similar soils: 80 percent
Byars, drained, and similar soils: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Byars, Ponded

Setting

Landform: Depressions, flats
Down-slope shape: Concave
Across-slope shape: Concave
Parent material: Clayey marine deposits

Typical profile

A - 0 to 10 inches: loam
Btg - 10 to 80 inches: clay

Properties and qualities

Slope: 0 to 1 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Very poorly drained
Runoff class: Negligible
Capacity of the most limiting layer to transmit water (Ksat): Moderately low to moderately high (0.06 to 0.20 in/hr)
Depth to water table: About 0 inches
Frequency of flooding: None
Frequency of ponding: Frequent
Available water storage in profile: High (about 9.8 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 6w
Hydrologic Soil Group: C/D

Description of Byars, Drained

Setting

Landform: Depressions, flats

Down-slope shape: Concave
Across-slope shape: Concave
Parent material: Clayey marine deposits

Typical profile

A - 0 to 10 inches: loam
Btg - 10 to 80 inches: clay

Properties and qualities

Slope: 0 to 1 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Very poorly drained
Runoff class: Very high
Capacity of the most limiting layer to transmit water (Ksat): Moderately low to moderately high (0.06 to 0.20 in/hr)
Depth to water table: About 0 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: High (about 9.8 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3w
Hydrologic Soil Group: C/D

Co—Coxville loam

Map Unit Setting

National map unit symbol: 3vdy
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Coxville, drained, and similar soils: 85 percent
Coxville, undrained, and similar soils: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Coxville, Drained

Setting

Landform: Depressions, carolina bays
Landform position (two-dimensional): Summit
Down-slope shape: Concave
Across-slope shape: Concave
Parent material: Clayey marine deposits

Typical profile

Ap - 0 to 9 inches: loam

Eg - 9 to 11 inches: loam
Btg - 11 to 72 inches: sandy clay
Cg - 72 to 80 inches: sandy clay loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Poorly drained
Runoff class: Low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high (0.20 to 0.57 in/hr)
Depth to water table: About 0 to 12 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Moderate (about 7.6 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3w
Hydrologic Soil Group: C/D

Description of Coxville, Undrained

Setting

Landform: Depressions, carolina bays
Landform position (two-dimensional): Summit
Down-slope shape: Concave
Across-slope shape: Concave
Parent material: Clayey marine deposits

Typical profile

A - 0 to 9 inches: loam
Eg - 9 to 11 inches: loam
Btg - 11 to 72 inches: sandy clay
Cg - 72 to 80 inches: sandy clay loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Poorly drained
Runoff class: Low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high (0.20 to 0.57 in/hr)
Depth to water table: About 0 to 12 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Moderate (about 7.6 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4w
Hydrologic Soil Group: C/D

Dn—Dunbar sandy loam

Map Unit Setting

National map unit symbol: 3vdz
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Dunbar, drained, and similar soils: 80 percent
Dunbar, undrained, and similar soils: 10 percent
Minor components: 4 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Dunbar, Drained

Setting

Landform: Flats on broad interstream divides
Landform position (two-dimensional): Summit
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Clayey marine deposits

Typical profile

Ap - 0 to 8 inches: fine sandy loam
Bt - 8 to 14 inches: clay loam
Btg - 14 to 62 inches: sandy clay
Cg - 62 to 92 inches: sandy clay

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Somewhat poorly drained
Runoff class: Very high
Capacity of the most limiting layer to transmit water (Ksat): Moderately high (0.20 to 0.57 in/hr)
Depth to water table: About 12 to 24 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: High (about 9.4 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2w
Hydrologic Soil Group: C/D

Description of Dunbar, Undrained

Setting

Landform: Flats on broad interstream divides
Landform position (two-dimensional): Summit
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Clayey marine deposits

Typical profile

A - 0 to 8 inches: fine sandy loam
Bt - 8 to 14 inches: clay loam
Btg - 14 to 62 inches: sandy clay
Cg - 62 to 92 inches: sandy clay

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Somewhat poorly drained
Runoff class: Very high
Capacity of the most limiting layer to transmit water (Ksat): Moderately high (0.20 to 0.57 in/hr)
Depth to water table: About 12 to 24 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: High (about 9.4 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3w
Hydrologic Soil Group: C/D

Minor Components

Coxville, undrained

Percent of map unit: 2 percent
Landform: Depressions, carolina bays
Landform position (two-dimensional): Summit
Down-slope shape: Concave
Across-slope shape: Concave

Rains, undrained

Percent of map unit: 2 percent
Landform: Broad interstream divides on marine terraces, carolina bays on marine terraces, flats on marine terraces
Landform position (two-dimensional): Summit
Down-slope shape: Linear
Across-slope shape: Linear

DpA—Duplin sandy loam, 0 to 2 percent slopes

Map Unit Setting

National map unit symbol: 3vf0
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: All areas are prime farmland

Map Unit Composition

Duplin and similar soils: 85 percent
Minor components: 5 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Duplin

Setting

Landform: Flats on broad interstream divides
Landform position (two-dimensional): Summit
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Clayey marine deposits

Typical profile

Ap - 0 to 8 inches: sandy loam
Bt - 8 to 84 inches: sandy clay
Cg - 84 to 100 inches: sandy clay loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Moderately well drained
Runoff class: Low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high (0.20 to 0.57 in/hr)
Depth to water table: About 24 to 36 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: High (about 9.3 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2w
Hydrologic Soil Group: C

Minor Components

Coxville, undrained

Percent of map unit: 3 percent
Landform: Depressions, carolina bays
Landform position (two-dimensional): Summit
Down-slope shape: Concave
Across-slope shape: Concave

Rains, undrained

Percent of map unit: 2 percent
Landform: Broad interstream divides on marine terraces, carolina bays on marine terraces, flats on marine terraces
Landform position (two-dimensional): Summit
Down-slope shape: Linear
Across-slope shape: Linear

DpB—Duplin sandy loam, 2 to 6 percent slopes

Map Unit Setting

National map unit symbol: 3vf1
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: All areas are prime farmland

Map Unit Composition

Duplin and similar soils: 90 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Duplin

Setting

Landform: Flats on broad interstream divides
Landform position (two-dimensional): Summit
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Clayey marine deposits

Typical profile

Ap - 0 to 8 inches: sandy loam
Bt - 8 to 84 inches: sandy clay
Cg - 84 to 100 inches: sandy clay loam

Properties and qualities

Slope: 2 to 6 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Moderately well drained
Runoff class: Low

Capacity of the most limiting layer to transmit water (Ksat): Moderately high (0.20 to 0.57 in/hr)
Depth to water table: About 24 to 36 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: High (about 9.3 inches)

Interpretive groups
Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2e
Hydrologic Soil Group: C

FaB—Faceville fine sandy loam, 2 to 6 percent slopes

Map Unit Setting
National map unit symbol: 3vf4
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: All areas are prime farmland

Map Unit Composition
Faceville and similar soils: 85 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Faceville

Setting
Landform: Ridges on marine terraces
Landform position (two-dimensional): Shoulder, summit
Landform position (three-dimensional): Crest
Down-slope shape: Convex
Across-slope shape: Convex
Parent material: Clayey marine deposits

Typical profile
Ap - 0 to 8 inches: fine sandy loam
E - 8 to 13 inches: fine sandy loam
Bt - 13 to 80 inches: clay

Properties and qualities
Slope: 2 to 6 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Well drained
Runoff class: Low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Moderate (about 8.1 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2e
Hydrologic Soil Group: B

GoA—Goldsboro loamy sand, 0 to 2 percent slopes

Map Unit Setting

National map unit symbol: 3vf5
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: All areas are prime farmland

Map Unit Composition

Goldsboro and similar soils: 90 percent
Minor components: 5 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Goldsboro

Setting

Landform: Broad interstream divides on marine terraces, flats on marine terraces
Landform position (two-dimensional): Summit
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Loamy marine deposits

Typical profile

Ap - 0 to 8 inches: loamy sand
E - 8 to 15 inches: loamy sand
Bt - 15 to 45 inches: sandy clay loam
Btg - 45 to 80 inches: sandy clay loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Moderately well drained
Runoff class: Low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 24 to 36 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Moderate (about 8.0 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2w
Hydrologic Soil Group: B

Minor Components

Rains, undrained

Percent of map unit: 5 percent
Landform: Broad interstream divides on marine terraces, carolina bays on marine terraces, flats on marine terraces
Landform position (two-dimensional): Summit
Down-slope shape: Linear
Across-slope shape: Linear

Jo—Johns sandy loam

Map Unit Setting

National map unit symbol: 3vf7
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Prime farmland if drained

Map Unit Composition

Johns and similar soils: 85 percent
Minor components: 5 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Johns

Setting

Landform: Stream terraces
Landform position (three-dimensional): Tread
Down-slope shape: Convex
Across-slope shape: Convex
Parent material: Loamy alluvium over sandy alluvium

Typical profile

Ap - 0 to 8 inches: fine sandy loam
E - 8 to 15 inches: fine sandy loam
Bt - 15 to 32 inches: sandy clay loam
2Cg - 32 to 80 inches: sand

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: 20 to 40 inches to strongly contrasting textural stratification
Natural drainage class: Moderately well drained
Runoff class: Low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 18 to 36 inches
Frequency of flooding: Rare

Frequency of ponding: None
Available water storage in profile: Low (about 4.3 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2w
Hydrologic Soil Group: C

Minor Components

Lumbee, undrained

Percent of map unit: 5 percent
Landform: Backswamps on stream terraces
Down-slope shape: Concave
Across-slope shape: Linear

JT—Johnston soils

Map Unit Setting

National map unit symbol: 3vf6
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Not prime farmland

Map Unit Composition

Johnston, undrained, and similar soils: 85 percent
Johnston, drained, and similar soils: 15 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Johnston, Undrained

Setting

Landform: Flood plains
Down-slope shape: Concave
Across-slope shape: Linear
Parent material: Sandy and loamy alluvium

Typical profile

A - 0 to 30 inches: mucky loam
Cg1 - 30 to 34 inches: loamy fine sand
Cg2 - 34 to 80 inches: fine sandy loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Very poorly drained
Runoff class: Ponded
Capacity of the most limiting layer to transmit water (Ksat): High (1.98 to 5.95 in/hr)
Depth to water table: About 0 inches

Frequency of flooding: Frequent
Frequency of ponding: Frequent
Available water storage in profile: High (about 9.4 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 7w
Hydrologic Soil Group: A/D

Description of Johnston, Drained

Setting

Landform: Flood plains
Down-slope shape: Concave
Across-slope shape: Linear
Parent material: Sandy and loamy alluvium

Typical profile

A - 0 to 30 inches: mucky loam
Cg1 - 30 to 34 inches: loamy fine sand
Cg2 - 34 to 80 inches: fine sandy loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Very poorly drained
Runoff class: Ponded
Capacity of the most limiting layer to transmit water (Ksat): High (1.98 to 5.95 in/hr)
Depth to water table: About 0 inches
Frequency of flooding: Frequent
Frequency of ponding: Frequent
Available water storage in profile: High (about 9.4 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4w
Hydrologic Soil Group: A/D

KaA—Kalmia loamy sand, 0 to 2 percent slopes

Map Unit Setting

National map unit symbol: 3vf8
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: All areas are prime farmland

Map Unit Composition

Kalmia and similar soils: 85 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Kalmia

Setting

Landform: Stream terraces
Landform position (three-dimensional): Tread
Down-slope shape: Convex
Across-slope shape: Convex
Parent material: Loamy alluvium over sandy alluvium

Typical profile

Ap - 0 to 8 inches: loamy sand
E - 8 to 12 inches: loamy sand
B - 12 to 32 inches: sandy clay loam
2C - 32 to 80 inches: loamy sand

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: 20 to 40 inches to strongly contrasting textural stratification
Natural drainage class: Well drained
Runoff class: Low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 40 to 72 inches
Frequency of flooding: Rare
Frequency of ponding: None
Available water storage in profile: Low (about 3.8 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 1
Hydrologic Soil Group: B

LaB—Lakeland sand, 0 to 6 percent slopes

Map Unit Setting

National map unit symbol: 3vfb
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Not prime farmland

Map Unit Composition

Lakeland and similar soils: 80 percent
Minor components: 5 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Lakeland

Setting

Landform: Ridges on marine terraces

Landform position (two-dimensional): Shoulder, summit
Landform position (three-dimensional): Crest
Down-slope shape: Convex
Across-slope shape: Convex
Parent material: Sandy marine deposits and/or eolian sands

Typical profile
A - 0 to 6 inches: sand
C1 - 6 to 48 inches: sand
C2 - 48 to 80 inches: sand

Properties and qualities
Slope: 0 to 6 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Excessively drained
Runoff class: Very low
Capacity of the most limiting layer to transmit water (Ksat): High to very high (5.95 to 19.98 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Low (about 4.0 inches)

Interpretive groups
Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4s
Hydrologic Soil Group: A

Minor Components

Leon
Percent of map unit: 5 percent
Landform: Flats on marine terraces
Down-slope shape: Linear
Across-slope shape: Concave

Le—Leon sand

Map Unit Setting
National map unit symbol: 3vf9
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Farmland of unique importance

Map Unit Composition
Leon and similar soils: 80 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Leon

Setting

Landform: Flats on marine terraces
Down-slope shape: Linear
Across-slope shape: Concave
Parent material: Sandy fluviomarine deposits and/or eolian sands

Typical profile

A - 0 to 3 inches: sand
E - 3 to 15 inches: sand
Bh - 15 to 30 inches: fine sand
BE - 30 to 33 inches: fine sand
E' - 33 to 66 inches: fine sand
B'h - 66 to 80 inches: fine sand

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Poorly drained
Runoff class: Very high
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.20 to 1.98 in/hr)
Depth to water table: About 0 to 12 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Low (about 3.8 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4w
Hydrologic Soil Group: A/D

Lu—Lumbee sandy loam

Map Unit Setting

National map unit symbol: 3vfc
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Prime farmland if drained

Map Unit Composition

Lumbee, drained, and similar soils: 85 percent
Lumbee, undrained, and similar soils: 15 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Lumbee, Drained

Setting

Landform: Backswamps on stream terraces

Down-slope shape: Concave
Across-slope shape: Linear
Parent material: Loamy alluvium over sandy alluvium

Typical profile

Ap - 0 to 6 inches: sandy loam
E - 6 to 14 inches: sandy loam
Btg - 14 to 36 inches: sandy clay loam
2Cg - 36 to 80 inches: loamy sand

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: 20 to 40 inches to strongly contrasting textural stratification
Natural drainage class: Poorly drained
Runoff class: Negligible
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 0 to 12 inches
Frequency of flooding: Rare
Frequency of ponding: None
Available water storage in profile: Low (about 4.4 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3w
Hydrologic Soil Group: B/D

Description of Lumbee, Undrained

Setting

Landform: Backswamps on stream terraces
Down-slope shape: Concave
Across-slope shape: Linear
Parent material: Loamy alluvium over sandy alluvium

Typical profile

Ap - 0 to 6 inches: sandy loam
E - 6 to 14 inches: sandy loam
Btg - 14 to 36 inches: sandy clay loam
2Cg - 36 to 80 inches: loamy sand

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: 20 to 40 inches to strongly contrasting textural stratification
Natural drainage class: Poorly drained
Runoff class: Negligible
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 0 to 12 inches
Frequency of flooding: Rare
Frequency of ponding: Occasional
Available water storage in profile: Low (about 4.4 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 6w

Hydrologic Soil Group: B/D

Ly—Lynchburg sandy loam

Map Unit Setting

National map unit symbol: 3vfd
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Prime farmland if drained

Map Unit Composition

Lynchburg, drained, and similar soils: 90 percent
Lynchburg, undrained, and similar soils: 4 percent
Minor components: 6 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Lynchburg, Drained

Setting

Landform: Broad interstream divides on marine terraces, flats on marine terraces
Landform position (two-dimensional): Summit
Down-slope shape: Concave
Across-slope shape: Linear
Parent material: Loamy marine deposits

Typical profile

Ap - 0 to 6 inches: sandy loam
E - 6 to 10 inches: sandy loam
Btg1 - 10 to 65 inches: sandy clay loam
Btg2 - 65 to 80 inches: clay

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Somewhat poorly drained
Runoff class: Low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.20 to 1.98 in/hr)
Depth to water table: About 6 to 18 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Moderate (about 7.3 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2w
Hydrologic Soil Group: A/D

Description of Lynchburg, Undrained

Setting

Landform: Broad interstream divides on marine terraces, flats on marine terraces
Landform position (two-dimensional): Summit
Down-slope shape: Concave
Across-slope shape: Linear
Parent material: Loamy marine deposits

Typical profile

Ap - 0 to 6 inches: sandy loam
E - 6 to 10 inches: sandy loam
Btg1 - 10 to 65 inches: sandy clay loam
Btg2 - 65 to 80 inches: clay

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Somewhat poorly drained
Runoff class: Low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.20 to 1.98 in/hr)
Depth to water table: About 6 to 18 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Moderate (about 7.3 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3w
Hydrologic Soil Group: A/D

Minor Components

Rains, undrained

Percent of map unit: 2 percent
Landform: Broad interstream divides on marine terraces, carolina bays on marine terraces, flats on marine terraces
Landform position (two-dimensional): Summit
Down-slope shape: Linear
Across-slope shape: Linear

Coxville, undrained

Percent of map unit: 2 percent
Landform: Depressions, carolina bays
Landform position (two-dimensional): Summit
Down-slope shape: Concave
Across-slope shape: Concave

Woodington, undrained

Percent of map unit: 2 percent
Landform: Depressions on marine terraces, broad interstream divides on marine terraces, flats on marine terraces
Down-slope shape: Linear
Across-slope shape: Concave

Toisnot, undrained

Percent of map unit: 0 percent
Landform: Broad interstream divides on marine terraces, carolina bays on marine terraces, flats on marine terraces
Landform position (two-dimensional): Summit
Down-slope shape: Linear
Across-slope shape: Linear

MaA—Marlboro sandy loam, 0 to 2 percent slopes

Map Unit Setting

National map unit symbol: 3vff
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: All areas are prime farmland

Map Unit Composition

Marlboro and similar soils: 90 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Marlboro

Setting

Landform: Ridges on marine terraces, broad interstream divides on marine terraces
Down-slope shape: Convex
Across-slope shape: Linear
Parent material: Clayey marine deposits

Typical profile

Ap - 0 to 10 inches: sandy loam
Bt1 - 10 to 71 inches: sandy clay
Bt2 - 71 to 80 inches: sandy clay

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Well drained
Runoff class: Low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 48 to 72 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: High (about 9.2 inches)

Interpretive groups

Land capability classification (irrigated): None specified

Land capability classification (nonirrigated): 1
Hydrologic Soil Group: B

MaB—Marlboro sandy loam, 2 to 6 percent slopes

Map Unit Setting

National map unit symbol: 3vfg
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: All areas are prime farmland

Map Unit Composition

Marlboro and similar soils: 90 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Marlboro

Setting

Landform: Ridges on marine terraces, broad interstream divides on marine terraces
Landform position (two-dimensional): Summit, shoulder
Landform position (three-dimensional): Crest
Down-slope shape: Convex
Across-slope shape: Convex
Parent material: Clayey marine deposits

Typical profile

Ap - 0 to 10 inches: sandy loam
Bt1 - 10 to 71 inches: sandy clay
Bt2 - 71 to 80 inches: sandy clay

Properties and qualities

Slope: 2 to 6 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Well drained
Runoff class: Low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 48 to 72 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: High (about 9.2 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2e
Hydrologic Soil Group: B

Mc—McColl loam

Map Unit Setting

National map unit symbol: 3vfh
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Not prime farmland

Map Unit Composition

Mccoll, ponded, and similar soils: 80 percent
Mccoll, drained, and similar soils: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Mccoll, Ponded

Setting

Landform: Carolina bays
Down-slope shape: Concave
Across-slope shape: Linear
Parent material: Clayey marine deposits

Typical profile

A - 0 to 9 inches: loam
Btg - 9 to 13 inches: clay
Btx - 13 to 42 inches: sandy clay loam
BC - 42 to 80 inches: sandy clay loam

Properties and qualities

Slope: 0 to 1 percent
Depth to restrictive feature: 12 to 40 inches to fragipan
Natural drainage class: Poorly drained
Runoff class: Negligible
Capacity of the most limiting layer to transmit water (Ksat): Moderately low to moderately high (0.06 to 0.20 in/hr)
Depth to water table: About 0 inches
Frequency of flooding: None
Frequency of ponding: Frequent
Available water storage in profile: Very low (about 1.9 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 6w
Hydrologic Soil Group: D

Description of Mccoll, Drained

Setting

Landform: Carolina bays
Down-slope shape: Concave
Across-slope shape: Linear

Parent material: Clayey marine deposits

Typical profile

Ap - 0 to 9 inches: loam
Btg - 9 to 13 inches: clay
Btx - 13 to 42 inches: sandy clay loam
BC - 42 to 80 inches: sandy clay loam

Properties and qualities

Slope: 0 to 1 percent
Depth to restrictive feature: 12 to 40 inches to fragipan
Natural drainage class: Poorly drained
Runoff class: Very high
Capacity of the most limiting layer to transmit water (Ksat): Moderately low to moderately high (0.06 to 0.20 in/hr)
Depth to water table: About 0 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Very low (about 1.9 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3w
Hydrologic Soil Group: D

NoA—Norfolk loamy sand, 0 to 2 percent slopes

Map Unit Setting

National map unit symbol: 3vfl
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: All areas are prime farmland

Map Unit Composition

Norfolk and similar soils: 85 percent
Minor components: 5 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Norfolk

Setting

Landform: Broad interstream divides on marine terraces, flats on marine terraces
Landform position (two-dimensional): Summit, shoulder
Landform position (three-dimensional): Crest
Down-slope shape: Convex
Across-slope shape: Convex
Parent material: Loamy marine deposits

Typical profile

Ap - 0 to 9 inches: loamy sand
E - 9 to 14 inches: loamy sand
Bt - 14 to 70 inches: sandy clay loam
C - 70 to 100 inches: sandy clay loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Well drained
Runoff class: Very low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 40 to 72 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Moderate (about 7.6 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 1
Hydrologic Soil Group: A

Minor Components

Rains, undrained

Percent of map unit: 5 percent
Landform: Broad interstream divides on marine terraces, carolina bays on marine terraces, flats on marine terraces
Landform position (two-dimensional): Summit
Down-slope shape: Linear
Across-slope shape: Linear

NoB—Norfolk loamy sand, 2 to 6 percent slopes

Map Unit Setting

National map unit symbol: 3vfm
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: All areas are prime farmland

Map Unit Composition

Norfolk and similar soils: 85 percent
Minor components: 5 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Norfolk

Setting

Landform: Broad interstream divides on marine terraces, flats on marine terraces
Landform position (two-dimensional): Summit, shoulder
Landform position (three-dimensional): Crest
Down-slope shape: Convex
Across-slope shape: Convex
Parent material: Loamy marine deposits

Typical profile

Ap - 0 to 9 inches: loamy sand
E - 9 to 14 inches: loamy sand
Bt - 14 to 70 inches: sandy clay loam
C - 70 to 100 inches: sandy clay loam

Properties and qualities

Slope: 2 to 6 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Well drained
Runoff class: Very low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 40 to 72 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Moderate (about 7.6 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2e
Hydrologic Soil Group: A

Minor Components

Bibb, undrained

Percent of map unit: 3 percent
Landform: Flood plains
Landform position (two-dimensional): Toeslope
Down-slope shape: Concave
Across-slope shape: Linear

Johnston, undrained

Percent of map unit: 2 percent
Landform: Flood plains
Down-slope shape: Concave
Across-slope shape: Linear

NsC—Norfolk and Faceville soils, 6 to 10 percent slopes

Map Unit Setting

National map unit symbol: 3vfn
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Norfolk and similar soils: 40 percent
Faceville and similar soils: 30 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Norfolk

Setting

Landform: Ridges on marine terraces, broad interstream divides on marine terraces
Landform position (two-dimensional): Shoulder
Landform position (three-dimensional): Crest
Down-slope shape: Convex
Across-slope shape: Convex
Parent material: Loamy marine deposits

Typical profile

Ap - 0 to 9 inches: loamy sand
E - 9 to 14 inches: loamy sand
Bt - 14 to 70 inches: sandy clay loam
C - 70 to 100 inches: sandy clay loam

Properties and qualities

Slope: 6 to 10 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Well drained
Runoff class: Medium
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 40 to 72 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Moderate (about 7.6 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3e
Hydrologic Soil Group: A

Description of Faceville

Setting

Landform: Ridges on marine terraces, broad interstream divides on marine terraces
Landform position (two-dimensional): Shoulder
Landform position (three-dimensional): Crest
Down-slope shape: Convex
Across-slope shape: Convex
Parent material: Clayey marine deposits

Typical profile

Ap - 0 to 8 inches: fine sandy loam
E - 8 to 13 inches: fine sandy loam
Bt - 13 to 80 inches: clay

Properties and qualities

Slope: 6 to 10 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Well drained
Runoff class: Medium
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Moderate (about 8.1 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4e
Hydrologic Soil Group: B

Pa—Pactolus loamy sand

Map Unit Setting

National map unit symbol: 3vfp
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Not prime farmland

Map Unit Composition

Pactolus and similar soils: 90 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Pactolus

Setting

Landform: Ridges on marine terraces, ridges on stream terraces

Landform position (three-dimensional): Tread
Down-slope shape: Concave, convex
Across-slope shape: Linear, convex
Parent material: Sandy fluviomarine deposits and/or eolian sands

Typical profile
Ap - 0 to 8 inches: loamy sand
C - 8 to 40 inches: loamy sand
Cg - 40 to 80 inches: loamy sand

Properties and qualities
Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Moderately well drained
Runoff class: Very low
Capacity of the most limiting layer to transmit water (Ksat): High to very high (5.95 to 19.98 in/hr)
Depth to water table: About 18 to 36 inches
Frequency of flooding: Rare
Frequency of ponding: None
Available water storage in profile: Low (about 4.2 inches)

Interpretive groups
Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3s
Hydrologic Soil Group: A

Pg—Pantego fine sandy loam

Map Unit Setting
National map unit symbol: 3vfq
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Prime farmland if drained

Map Unit Composition
Pantego, drained, and similar soils: 80 percent
Pantego, undrained, and similar soils: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Pantego, Drained

Setting
Landform: Broad interstream divides on marine terraces, flats on marine terraces
Down-slope shape: Linear
Across-slope shape: Concave
Parent material: Loamy marine deposits

Typical profile
Ap - 0 to 10 inches: loam
A - 10 to 18 inches: loam

Bt - 18 to 27 inches: sandy clay loam
Btg - 27 to 80 inches: sandy clay loam

Properties and qualities

Slope: 0 to 1 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Very poorly drained
Runoff class: Very low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 0 to 12 inches
Frequency of flooding: Rare
Frequency of ponding: None
Available water storage in profile: High (about 10.2 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3w
Hydrologic Soil Group: B/D

Description of Pantego, Undrained

Setting

Landform: Broad interstream divides on marine terraces, flats on marine terraces
Down-slope shape: Linear
Across-slope shape: Concave
Parent material: Loamy marine deposits

Typical profile

A - 0 to 18 inches: loam
Bt - 18 to 27 inches: sandy clay loam
Btg - 27 to 80 inches: sandy clay loam

Properties and qualities

Slope: 0 to 1 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Very poorly drained
Runoff class: Very low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 0 to 12 inches
Frequency of flooding: Rare
Frequency of ponding: None
Available water storage in profile: High (about 10.2 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 6w
Hydrologic Soil Group: B/D

Pm—Plummer and Osier soils

Map Unit Setting

National map unit symbol: 3vfr
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Not prime farmland

Map Unit Composition

Plummer, undrained, and similar soils: 40 percent
Osier, undrained, and similar soils: 30 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Plummer, Undrained

Setting

Landform: Depressions, drainageways, flats
Landform position (two-dimensional): Toeslope
Down-slope shape: Concave
Across-slope shape: Concave
Parent material: Loamy and sandy marine deposits

Typical profile

A - 0 to 9 inches: loamy sand
Eg - 9 to 50 inches: loamy sand
Btg - 50 to 80 inches: sandy loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Poorly drained
Runoff class: Very high
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.20 to 1.98 in/hr)
Depth to water table: About 0 to 12 inches
Frequency of flooding: Very rare
Frequency of ponding: None
Available water storage in profile: Low (about 4.6 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4w
Hydrologic Soil Group: A/D

Description of Osier, Undrained

Setting

Landform: Depressions, drainageways, flats

Landform position (two-dimensional): Toeslope
Down-slope shape: Concave
Across-slope shape: Concave
Parent material: Sandy fluviomarine deposits

Typical profile

A - 0 to 8 inches: loamy sand
Cg1 - 8 to 48 inches: loamy sand
Cg2 - 48 to 80 inches: coarse sand

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Poorly drained
Runoff class: Very high
Capacity of the most limiting layer to transmit water (Ksat): High to very high (5.95 to 19.98 in/hr)
Depth to water table: About 0 to 12 inches
Frequency of flooding: Frequent
Frequency of ponding: None
Available water storage in profile: Low (about 3.8 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 5w
Hydrologic Soil Group: A/D

PoB—Pocalla loamy sand, 0 to 3 percent slopes

Map Unit Setting

National map unit symbol: 3vfs
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Pocalla and similar soils: 90 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Pocalla

Setting

Landform: Ridges on marine terraces, flats on marine terraces
Down-slope shape: Convex
Across-slope shape: Convex
Parent material: Loamy and sandy marine deposits

Typical profile

Ap - 0 to 8 inches: loamy sand

E - 8 to 23 inches: loamy sand
Bt - 23 to 36 inches: sandy loam
E' - 36 to 46 inches: loamy sand
Btv - 46 to 80 inches: sandy clay loam

Properties and qualities

Slope: 0 to 3 percent
Depth to restrictive feature: 40 to 60 inches to plinthite
Natural drainage class: Somewhat excessively drained
Runoff class: Very low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 40 to 60 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Low (about 4.7 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2s
Hydrologic Soil Group: A

Pr—Ponzer muck, siliceous subsoil variant (Croatan)

Map Unit Setting

National map unit symbol: 3vft
Elevation: 20 to 160 feet
Mean annual precipitation: 40 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 200 to 280 days
Farmland classification: Not prime farmland

Map Unit Composition

Croatan, undrained, and similar soils: 80 percent
Croatan, drained, and similar soils: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Croatan, Undrained

Setting

Landform: Pocosins
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Woody organic material

Typical profile

Oa - 0 to 28 inches: muck
Ag - 28 to 33 inches: mucky sandy loam
Cg1 - 33 to 60 inches: sandy clay loam
Cg2 - 60 to 80 inches: loamy sand

Properties and qualities

Slope: 0 to 1 percent

Depth to restrictive feature: More than 80 inches
Natural drainage class: Very poorly drained
Runoff class: Negligible
Capacity of the most limiting layer to transmit water (Ksat): Very low to high (0.00 to 1.98 in/hr)
Depth to water table: About 0 to 6 inches
Frequency of flooding: Rare
Frequency of ponding: None
Available water storage in profile: Very high (about 16.1 inches)

Interpretive groups
Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 7w
Hydrologic Soil Group: B/D

Description of Croatan, Drained

Setting
Landform: Pocosins
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Woody organic material

Typical profile
Oa - 0 to 28 inches: muck
Ag - 28 to 33 inches: mucky sandy loam
Cg1 - 33 to 60 inches: sandy clay loam
Cg2 - 60 to 80 inches: loamy sand

Properties and qualities
Slope: 0 to 1 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Very poorly drained
Runoff class: Negligible
Capacity of the most limiting layer to transmit water (Ksat): Very low to high (0.00 to 1.98 in/hr)
Depth to water table: About 0 to 12 inches
Frequency of flooding: Rare
Frequency of ponding: None
Available water storage in profile: Very high (about 16.1 inches)

Interpretive groups
Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4w
Hydrologic Soil Group: B/D

Pt—Portsmouth loam

Map Unit Setting
National map unit symbol: 3vfv
Elevation: 20 to 160 feet

Mean annual precipitation: 40 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 200 to 280 days
Farmland classification: Prime farmland if drained

Map Unit Composition

Portsmouth, drained, and similar soils: 80 percent
Portsmouth, undrained, and similar soils: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Portsmouth, Drained

Setting

Landform: Depressions on stream terraces, flats on marine terraces
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Loamy fluviomarine deposits over sandy fluviomarine deposits

Typical profile

Ap - 0 to 12 inches: loam
Eg - 12 to 19 inches: loam
BEg - 19 to 23 inches: loam
Btg - 23 to 35 inches: sandy clay loam
BCg - 35 to 38 inches: sandy loam
2Cg1 - 38 to 48 inches: sand
2Cg2 - 48 to 80 inches: sand

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: 20 to 40 inches to strongly contrasting textural stratification
Natural drainage class: Very poorly drained
Runoff class: Very high
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 0 to 12 inches
Frequency of flooding: Rare
Frequency of ponding: None
Available water storage in profile: Low (about 5.8 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3w
Hydrologic Soil Group: B/D

Description of Portsmouth, Undrained

Setting

Landform: Depressions on stream terraces, flats on marine terraces
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Loamy fluviomarine deposits over sandy fluviomarine deposits

Typical profile

A - 0 to 12 inches: loam
Eg - 12 to 19 inches: loam
BEg - 19 to 23 inches: loam

Btg - 23 to 35 inches: sandy clay loam
BCg - 35 to 38 inches: sandy loam
2Cg1 - 38 to 48 inches: sand
2Cg2 - 48 to 80 inches: sand

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: 20 to 40 inches to strongly contrasting textural stratification
Natural drainage class: Very poorly drained
Runoff class: Very high
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 0 to 12 inches
Frequency of flooding: Rare
Frequency of ponding: Rare
Available water storage in profile: Low (about 5.8 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 6w
Hydrologic Soil Group: B/D

Ra—Rains sandy loam

Map Unit Setting

National map unit symbol: 3vfw
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Prime farmland if drained

Map Unit Composition

Rains, drained, and similar soils: 80 percent
Rains, undrained, and similar soils: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Rains, Drained

Setting

Landform: Broad interstream divides on marine terraces, carolina bays on marine terraces, flats on marine terraces
Landform position (two-dimensional): Summit
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Loamy marine deposits

Typical profile

A - 0 to 7 inches: sandy loam
Eg - 7 to 12 inches: fine sandy loam

Btg1 - 12 to 20 inches: sandy loam
Btg2 - 20 to 62 inches: sandy clay loam
Cg - 62 to 85 inches: sandy clay loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Poorly drained
Runoff class: Very low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.20 to 1.98 in/hr)
Depth to water table: About 0 to 12 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: High (about 9.4 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3w
Hydrologic Soil Group: B/D

Description of Rains, Undrained

Setting

Landform: Broad interstream divides on marine terraces, carolina bays on marine terraces, flats on marine terraces
Landform position (two-dimensional): Summit
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Loamy marine deposits

Typical profile

A - 0 to 7 inches: sandy loam
Eg - 7 to 12 inches: fine sandy loam
Btg1 - 12 to 20 inches: sandy loam
Btg2 - 20 to 62 inches: sandy clay loam
Cg - 62 to 85 inches: sandy clay loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Poorly drained
Runoff class: Very low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.20 to 1.98 in/hr)
Depth to water table: About 0 to 12 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: High (about 9.4 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4w
Hydrologic Soil Group: B/D

Ru—Rutlege loamy sand

Map Unit Setting

National map unit symbol: 3vfx
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Not prime farmland

Map Unit Composition

Rutlege, undrained, and similar soils: 80 percent
Rutlege, drained, and similar soils: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Rutlege, Undrained

Setting

Landform: Depressions, drainageways, flats
Landform position (two-dimensional): Toeslope
Down-slope shape: Concave
Across-slope shape: Concave
Parent material: Sandy fluviomarine deposits and/or eolian sands

Typical profile

A - 0 to 15 inches: loamy sand
Cg - 15 to 80 inches: sand

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Very poorly drained
Runoff class: Very high
Capacity of the most limiting layer to transmit water (Ksat): High to very high (5.95 to 19.98 in/hr)
Depth to water table: About 0 to 6 inches
Frequency of flooding: Rare
Frequency of ponding: None
Available water storage in profile: Low (about 4.6 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 5w
Hydrologic Soil Group: A/D

Description of Rutlege, Drained

Setting

Landform: Depressions, drainageways, flats
Landform position (two-dimensional): Toeslope

Down-slope shape: Concave
Across-slope shape: Concave
Parent material: Sandy fluviomarine deposits and/or eolian sands

Typical profile

A - 0 to 15 inches: loamy sand
Cg - 15 to 80 inches: sand

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Very poorly drained
Runoff class: Very high
Capacity of the most limiting layer to transmit water (Ksat): High to very high (5.95 to 19.98 in/hr)
Depth to water table: About 0 to 6 inches
Frequency of flooding: Rare
Frequency of ponding: None
Available water storage in profile: Low (about 4.6 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4w
Hydrologic Soil Group: A/D

Ta—Toisnot loam

Map Unit Setting

National map unit symbol: 3vfy
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Not prime farmland

Map Unit Composition

Toisnot, undrained, and similar soils: 80 percent
Toisnot, drained, and similar soils: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Toisnot, Undrained

Setting

Landform: Broad interstream divides on marine terraces, carolina bays on marine terraces, flats on marine terraces
Landform position (two-dimensional): Summit
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Loamy fluviomarine deposits

Typical profile

A - 0 to 6 inches: loam
Eg - 6 to 13 inches: sandy loam
E/Btg - 13 to 28 inches: sandy loam
Ex - 28 to 45 inches: sandy loam
Btg - 45 to 61 inches: sandy clay loam
2Cg - 61 to 90 inches: sandy clay

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: 20 to 40 inches to fragipan
Natural drainage class: Poorly drained
Runoff class: Low
Capacity of the most limiting layer to transmit water (Ksat): Moderately low to moderately high (0.06 to 0.20 in/hr)
Depth to water table: About 0 to 12 inches
Frequency of flooding: None
Frequency of ponding: Frequent
Available water storage in profile: Low (about 3.7 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 5w
Hydrologic Soil Group: C/D

Description of Toisnot, Drained

Setting

Landform: Broad interstream divides on marine terraces, carolina bays on marine terraces, flats on marine terraces
Landform position (two-dimensional): Summit
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Loamy fluviomarine deposits

Typical profile

Ap - 0 to 6 inches: loam
Eg - 6 to 13 inches: sandy loam
E/Btg - 13 to 28 inches: sandy loam
Ex - 28 to 45 inches: sandy loam
Btg - 45 to 61 inches: sandy clay loam
2Cg - 61 to 90 inches: sandy clay

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: 20 to 40 inches to fragipan
Natural drainage class: Poorly drained
Runoff class: Low
Capacity of the most limiting layer to transmit water (Ksat): Moderately low to moderately high (0.06 to 0.20 in/hr)
Depth to water table: About 0 to 12 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Low (about 3.7 inches)

Interpretive groups

Land capability classification (irrigated): None specified

Land capability classification (nonirrigated): 4w
Hydrologic Soil Group: C/D

To—Torhunta loam

Map Unit Setting

National map unit symbol: 3vfz
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Prime farmland if drained

Map Unit Composition

Torhunta, drained, and similar soils: 80 percent
Torhunta, undrained, and similar soils: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Torhunta, Drained

Setting

Landform: Depressions on stream terraces, carolina bays on marine terraces, flats on marine terraces
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Sandy and loamy alluvium and/or fluviomarine deposits

Typical profile

A - 0 to 15 inches: mucky fine sandy loam
Bg - 15 to 40 inches: fine sandy loam
Cg - 40 to 80 inches: loamy sand

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Very poorly drained
Runoff class: Very low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 5.95 in/hr)
Depth to water table: About 0 to 12 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Low (about 5.8 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3w
Hydrologic Soil Group: A/D

Description of Torhunta, Undrained

Setting

Landform: Depressions on stream terraces, carolina bays on marine terraces, flats on marine terraces
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Sandy and loamy alluvium and/or fluviomarine deposits

Typical profile

A - 0 to 15 inches: mucky fine sandy loam
Bg - 15 to 40 inches: fine sandy loam
Cg - 40 to 80 inches: loamy sand

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Very poorly drained
Runoff class: Very low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 5.95 in/hr)
Depth to water table: About 0 to 12 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Low (about 5.8 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 6w
Hydrologic Soil Group: A/D

Ud—Udorthents, loamy

Map Unit Setting

National map unit symbol: 3vg1
Elevation: 20 to 330 feet
Mean annual precipitation: 40 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 200 to 280 days
Farmland classification: Not prime farmland

Map Unit Composition

Udorthents and similar soils: 100 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Udorthents

Setting

Down-slope shape: Linear
Across-slope shape: Linear

Parent material: Loamy mine spoil or earthy fill

Typical profile

C - 0 to 80 inches: sandy clay loam

Properties and qualities

Slope: 0 to 6 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Well drained
Runoff class: Low
Capacity of the most limiting layer to transmit water (Ksat): Very low to high (0.00 to 1.98 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Moderate (about 8.4 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 7e
Hydrologic Soil Group: C

W—Water

Map Unit Composition

Water: 100 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Water

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 8w

WaB—Wagram loamy sand, 0 to 6 percent slopes

Map Unit Setting

National map unit symbol: 3vg3
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Wagram and similar soils: 90 percent
Minor components: 5 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Wagram

Setting

Landform: Ridges on marine terraces, broad interstream divides on marine terraces
Landform position (two-dimensional): Shoulder, summit
Landform position (three-dimensional): Crest
Down-slope shape: Convex
Across-slope shape: Convex
Parent material: Loamy marine deposits

Typical profile

Ap - 0 to 8 inches: loamy sand
E - 8 to 24 inches: loamy sand
Bt - 24 to 75 inches: sandy clay loam
BC - 75 to 83 inches: sandy loam

Properties and qualities

Slope: 0 to 6 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Well drained
Runoff class: Low
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 60 to 80 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Moderate (about 6.7 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2s
Hydrologic Soil Group: A

Minor Components

Bibb, undrained

Percent of map unit: 3 percent
Landform: Flood plains
Landform position (two-dimensional): Toeslope
Down-slope shape: Concave
Across-slope shape: Linear

Johnston, undrained

Percent of map unit: 2 percent
Landform: Flood plains
Down-slope shape: Concave
Across-slope shape: Linear

WaC—Wagram loamy sand, 6 to 10 percent slopes

Map Unit Setting

National map unit symbol: 3vg4
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Wagram and similar soils: 85 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Wagram

Setting

Landform: Ridges on marine terraces, broad interstream divides on marine terraces
Landform position (two-dimensional): Shoulder
Landform position (three-dimensional): Crest
Down-slope shape: Convex
Across-slope shape: Convex
Parent material: Loamy marine deposits

Typical profile

Ap - 0 to 8 inches: loamy sand
E - 8 to 24 inches: loamy sand
Bt - 24 to 75 inches: sandy clay loam
BC - 75 to 83 inches: sandy loam

Properties and qualities

Slope: 6 to 10 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Well drained
Runoff class: Medium
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.57 to 1.98 in/hr)
Depth to water table: About 60 to 80 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Moderate (about 6.7 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3s
Hydrologic Soil Group: A

WkB—Wakulla sand, 0 to 6 percent slopes

Map Unit Setting

National map unit symbol: 3vg5
Elevation: 80 to 330 feet
Mean annual precipitation: 38 to 55 inches
Mean annual air temperature: 59 to 70 degrees F
Frost-free period: 210 to 265 days
Farmland classification: Not prime farmland

Map Unit Composition

Wakulla and similar soils: 90 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Wakulla

Setting

Landform: Ridges on marine terraces, broad interstream divides on marine terraces
Landform position (two-dimensional): Shoulder, summit
Landform position (three-dimensional): Crest
Down-slope shape: Convex
Across-slope shape: Convex
Parent material: Sandy and loamy marine deposits and/or eolian sands

Typical profile

A - 0 to 7 inches: sand
E - 7 to 24 inches: sand
Bt - 24 to 42 inches: loamy sand
C - 42 to 85 inches: sand

Properties and qualities

Slope: 0 to 6 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Somewhat excessively drained
Runoff class: Very low
Capacity of the most limiting layer to transmit water (Ksat): High to very high (1.98 to 19.98 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Very low (about 2.7 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3s
Hydrologic Soil Group: A

Soil Information for All Uses

Soil Reports

The Soil Reports section includes various formatted tabular and narrative reports (tables) containing data for each selected soil map unit and each component of each unit. No aggregation of data has occurred as is done in reports in the Soil Properties and Qualities and Suitabilities and Limitations sections.

The reports contain soil interpretive information as well as basic soil properties and qualities. A description of each report (table) is included.

Waste Management

This folder contains a collection of tabular reports that present soil interpretations related to waste management. The reports (tables) include all selected map units and components for each map unit, limiting features and interpretive ratings. Waste management interpretations are tools designed to guide the user in evaluating soils for use of organic wastes and wastewater as productive resources. Example interpretations include land application of manure, food processing waste, and municipal sewage sludge, and disposal of wastewater by irrigation or overland flow process.

Agricultural Disposal of Manure, Food-Processing Waste, and Sewage Sludge

Soil properties are important considerations in areas where soils are used as sites for the treatment and disposal of organic waste and wastewater. Selection of soils with properties that favor waste management can help to prevent environmental damage.

This table shows the degree and kind of soil limitations affecting the treatment of agricultural waste, including municipal and food-processing wastewater and effluent from lagoons or storage ponds. Municipal wastewater is the waste stream from a municipality. It contains domestic waste and may contain industrial waste. It may have received primary or secondary treatment. It is rarely untreated sewage. Food-processing wastewater results from the preparation of fruits, vegetables, milk, cheese, and meats for public consumption. In places it is high in content of sodium and chloride. In the context of this table, the effluent in lagoons and storage ponds is from facilities used to treat or store food-processing wastewater or domestic or animal waste. Domestic and food-processing wastewater is very dilute, and the effluent from the facilities that treat or store it commonly is very low in content of carbonaceous and nitrogenous material; the content of nitrogen commonly ranges from 10 to 30 milligrams per liter. The wastewater from animal waste treatment lagoons or storage ponds, however, has much higher concentrations of these materials, mainly because the manure has not been diluted as much as the domestic waste. The content of nitrogen in this wastewater generally ranges from 50 to 2,000 milligrams per liter. When wastewater is applied, checks should be made to ensure that nitrogen, heavy metals, and salts are not added in excessive amounts.

The ratings in the table are for waste management systems that not only dispose of and treat organic waste or wastewater but also are beneficial to crops. The ratings are both verbal and numerical. Rating class terms indicate the extent to which the soils are limited by all of the soil features that affect agricultural waste management. *Not limited* indicates that the soil has features that are very favorable for the specified use. Good performance and very low maintenance can be expected. *Somewhat limited* indicates that the soil has features that are moderately favorable for the specified use. The limitations can be overcome or minimized by special planning, design, or installation. Fair performance and moderate maintenance can be expected. *Very limited* indicates that the soil has one or more features that are unfavorable for the specified use. The limitations generally cannot be overcome without major soil reclamation, special design, or expensive installation procedures. Poor performance and high maintenance can be expected.

Numerical ratings in the tables indicate the severity of individual limitations. The ratings are shown as decimal fractions ranging from 0.01 to 1.00. They indicate gradations between the point at which a soil feature has the greatest negative impact on the use (1.00) and the point at which the soil feature is not a limitation (0.00).

Application of manure and food-processing waste not only disposes of waste material but also can improve crop production by increasing the supply of nutrients in the soils where the material is applied. Manure is the excrement of livestock and poultry, and food-processing waste is damaged fruit and vegetables and the peelings, stems, leaves, pits, and soil particles removed in food preparation. The manure and food-processing waste are solid, slurry, or liquid. Their nitrogen content varies. A high content of nitrogen limits the application rate. Toxic or otherwise dangerous wastes, such as those mixed with the lye used in food processing, are not considered in the ratings.

The ratings are based on the soil properties that affect absorption, plant growth, microbial activity, erodibility, the rate at which the waste is applied, and the method by which the waste is applied. The properties that affect absorption include saturated hydraulic conductivity (Ksat), depth to a water table, ponding, the sodium adsorption ratio, depth to bedrock or a cemented pan, and available water capacity. The properties that affect plant growth and microbial activity include reaction, the sodium adsorption ratio, salinity, and bulk density. The wind erodibility group, the soil erosion factor K, and slope are considered in estimating the likelihood that wind erosion or water erosion will transport the waste material from the application site. Stones, cobbles, a water table, ponding, and flooding can hinder the application of waste. Permanently frozen soils are unsuitable for waste treatment.

Application of sewage sludge not only disposes of waste material but also can improve crop production by increasing the supply of nutrients in the soils where the material is applied. In the context of this table, sewage sludge is the residual product of the treatment of municipal sewage. The solid component consists mainly of cell mass, primarily bacteria cells that developed during secondary treatment and have incorporated soluble organics into their own bodies. The sludge has small amounts of sand, silt, and other solid debris. The content of nitrogen varies. Some sludge has constituents that are toxic to plants or hazardous to the food chain, such as heavy metals and exotic organic compounds, and should be analyzed chemically prior to use.

The content of water in the sludge ranges from about 98 percent to less than 40 percent. The sludge is considered liquid if it is more than about 90 percent water, slurry if it is about 50 to 90 percent water, and solid if it is less than about 50 percent water.

The ratings in the table are based on the soil properties that affect absorption, plant growth, microbial activity, erodibility, the rate at which the sludge is applied, and the method by which the sludge is applied. The properties that affect absorption, plant growth, and microbial activity include Ksat, depth to a water table, ponding, the sodium adsorption ratio, depth to bedrock or a cemented pan, available water capacity, reaction, salinity, and bulk density. The wind erodibility group, the soil erosion factor K, and slope are considered in estimating the likelihood that wind erosion or water erosion will transport the waste material from the application site. Stones, cobbles, a water table, ponding, and flooding can hinder the application of sludge. Permanently frozen soils are unsuitable for waste treatment.

Report—Agricultural Disposal of Manure, Food-Processing Waste, and Sewage Sludge

[Onsite investigation may be needed to validate the interpretations in this table and to confirm the identity of the soil on a given site. The numbers in the value columns range from 0.01 to 1.00. The larger the value, the greater the potential limitation. The table shows only the top five limitations for any given soil. The soil may have additional limitations]

Agricultural Disposal of Manure, Food-Processing Waste, and Sewage Sludge–Cumberland County, North Carolina					
Map symbol and soil name	Pct. of map unit	Application of manure and food-processing waste		Application of sewage sludge	
		Rating class and limiting features	Value	Rating class and limiting features	Value
AuA—Autryville loamy sand, 0 to 2 percent slopes					
Autryville	90	Very limited		Very limited	
		Filtering capacity	1.00	Filtering capacity	1.00
		Leaching	0.45	Too acid	0.77
		Too acid	0.22		
CaB—Candor sand, 1 to 8 percent slopes					
Candor	80	Very limited		Very limited	
		Filtering capacity	1.00	Filtering capacity	1.00
		Too acid	0.62	Too acid	1.00
		Leaching	0.45	Droughty	0.04
		Droughty	0.04		

Agricultural Disposal of Manure, Food-Processing Waste, and Sewage Sludge–Cumberland County, North Carolina					
Map symbol and soil name	Pct. of map unit	Application of manure and food-processing waste		Application of sewage sludge	
		Rating class and limiting features	Value	Rating class and limiting features	Value
GoA—Goldsboro loamy sand, 0 to 2 percent slopes					
Goldsboro	90	Somewhat limited		Very limited	
		Depth to saturated zone	0.99	Too acid	1.00
		Too acid	0.68	Depth to saturated zone	0.99
		Low adsorption	0.01		
JT—Johnston loam					
Johnston, undrained	85	Very limited		Very limited	
		Ponding	1.00	Ponding	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Flooding	1.00	Flooding	1.00
		Leaching	0.90	Too acid	1.00
		Too acid	0.50		
Johnston, drained	15	Very limited		Very limited	
		Filtering capacity	1.00	Filtering capacity	1.00
		Ponding	1.00	Ponding	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Flooding	1.00	Flooding	1.00
		Leaching	0.90	Too acid	1.00
Pa—Pactolus loamy sand					
Pactolus	90	Very limited		Very limited	
		Filtering capacity	1.00	Filtering capacity	1.00
		Depth to saturated zone	0.99	Too acid	1.00
		Too acid	0.78	Depth to saturated zone	0.99
		Leaching	0.45	Droughty	0.11
		Droughty	0.11		
WaB—Wagram loamy sand, 0 to 6 percent slopes					
Wagram	90	Very limited		Very limited	
		Filtering capacity	1.00	Filtering capacity	1.00
		Leaching	0.45	Too acid	0.92
		Too acid	0.32		

Custom Soil Resource Report

Agricultural Disposal of Manure, Food-Processing Waste, and Sewage Sludge–Robeson County, North Carolina					
Map symbol and soil name	Pct. of map unit	Application of manure and food-processing waste		Application of sewage sludge	
		Rating class and limiting features	Value	Rating class and limiting features	Value
BB—Bibb soils					
Bibb, undrained	80	Very limited		Very limited	
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Flooding	1.00	Flooding	1.00
		Leaching	0.90	Too acid	1.00
		Too acid	0.73		
Johnston, undrained	10	Very limited		Very limited	
		Ponding	1.00	Ponding	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Flooding	1.00	Flooding	1.00
		Leaching	0.90	Too acid	1.00
		Too acid	0.50		
Bp—Borrow pit					
Pits, sand	100	Not rated		Not rated	
By—Byars loam					
Byars, ponded	80	Very limited		Very limited	
		Slow water movement	1.00	Ponding	1.00
		Ponding	1.00	Depth to saturated zone	1.00
		Depth to saturated zone	1.00	Slow water movement	1.00
		Too acid	0.73	Too acid	1.00
		Leaching	0.50		
Byars, drained	10	Very limited		Very limited	
		Slow water movement	1.00	Depth to saturated zone	1.00
		Depth to saturated zone	1.00	Slow water movement	1.00
		Too acid	0.73	Too acid	1.00
		Leaching	0.50		
		Low adsorption	0.04		

Custom Soil Resource Report

Agricultural Disposal of Manure, Food-Processing Waste, and Sewage Sludge–Robeson County, North Carolina					
Map symbol and soil name	Pct. of map unit	Application of manure and food-processing waste		Application of sewage sludge	
		Rating class and limiting features	Value	Rating class and limiting features	Value
Co—Coxville loam					
Coxville, drained	85	Very limited		Very limited	
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Too acid	0.68	Too acid	1.00
		Low adsorption	0.65	Slow water movement	0.22
		Leaching	0.50	Low adsorption	0.01
		Slow water movement	0.30		
Coxville, undrained	10	Very limited		Very limited	
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Too acid	0.68	Too acid	1.00
		Low adsorption	0.65	Slow water movement	0.22
		Leaching	0.50	Low adsorption	0.01
		Slow water movement	0.30		
Dn—Dunbar sandy loam					
Dunbar, drained	80	Very limited		Very limited	
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Leaching	0.50	Too acid	1.00
		Too acid	0.50	Slow water movement	0.22
		Slow water movement	0.30		
		Low adsorption	0.20		
Dunbar, undrained	10	Very limited		Very limited	
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Leaching	0.50	Too acid	1.00
		Too acid	0.50	Slow water movement	0.22
		Slow water movement	0.30		
		Low adsorption	0.20		
DpA—Duplin sandy loam, 0 to 2 percent slopes					
Duplin	85	Somewhat limited		Somewhat limited	
		Depth to saturated zone	0.99	Depth to saturated zone	0.99
		Low adsorption	0.42	Slow water movement	0.22
		Slow water movement	0.30	Too acid	0.21
		Too acid	0.05		

Agricultural Disposal of Manure, Food-Processing Waste, and Sewage Sludge–Robeson County, North Carolina					
Map symbol and soil name	Pct. of map unit	Application of manure and food-processing waste		Application of sewage sludge	
		Rating class and limiting features	Value	Rating class and limiting features	Value
DpB—Duplin sandy loam, 2 to 6 percent slopes					
Duplin	90	Somewhat limited		Somewhat limited	
		Depth to saturated zone	0.99	Depth to saturated zone	0.99
		Low adsorption	0.42	Slow water movement	0.22
		Slow water movement	0.30	Too acid	0.08
		Too acid	0.02		
FaB—Faceville fine sandy loam, 2 to 6 percent slopes					
Faceville	85	Somewhat limited		Somewhat limited	
		Too acid	0.22	Too acid	0.77
		Low adsorption	0.17		
GoA—Goldsboro loamy sand, 0 to 2 percent slopes					
Goldsboro	90	Somewhat limited		Very limited	
		Depth to saturated zone	0.99	Too acid	1.00
		Too acid	0.68	Depth to saturated zone	0.99
		Low adsorption	0.01		
Jo—Johns sandy loam					
Johns	85	Very limited		Very limited	
		Filtering capacity	1.00	Filtering capacity	1.00
		Depth to saturated zone	0.99	Too acid	1.00
		Too acid	0.68	Depth to saturated zone	0.99
		Strongly contrasting textural stratification	0.29	Flooding	0.40
		Low adsorption	0.02	Strongly contrasting textural stratification	0.29

Custom Soil Resource Report

Agricultural Disposal of Manure, Food-Processing Waste, and Sewage Sludge–Robeson County, North Carolina					
Map symbol and soil name	Pct. of map unit	Application of manure and food-processing waste		Application of sewage sludge	
		Rating class and limiting features	Value	Rating class and limiting features	Value
JT—Johnston soils					
Johnston, undrained	85	Very limited		Very limited	
		Ponding	1.00	Ponding	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Flooding	1.00	Flooding	1.00
		Leaching	0.90	Too acid	1.00
		Too acid	0.50		
Johnston, drained	15	Very limited		Very limited	
		Filtering capacity	1.00	Filtering capacity	1.00
		Ponding	1.00	Ponding	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Flooding	1.00	Flooding	1.00
		Leaching	0.90	Too acid	1.00
KaA—Kalmia loamy sand, 0 to 2 percent slopes					
Kalmia	85	Very limited		Very limited	
		Filtering capacity	1.00	Filtering capacity	1.00
		Too acid	0.68	Too acid	1.00
		Strongly contrasting textural stratification	0.29	Flooding	0.40
		Low adsorption	0.12	Strongly contrasting textural stratification	0.29
LaB—Lakeland sand, 0 to 6 percent slopes					
Lakeland	80	Very limited		Very limited	
		Filtering capacity	1.00	Filtering capacity	1.00
		Leaching	0.45	Too acid	0.92
		Too acid	0.32	Droughty	0.21
		Droughty	0.21		
Le—Leon sand					
Leon	80	Very limited		Very limited	
		Filtering capacity	1.00	Filtering capacity	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Leaching	0.90	Too acid	0.99
		Too acid	0.43	Droughty	0.14
		Droughty	0.14		

Agricultural Disposal of Manure, Food-Processing Waste, and Sewage Sludge–Robeson County, North Carolina					
Map symbol and soil name	Pct. of map unit	Application of manure and food-processing waste		Application of sewage sludge	
		Rating class and limiting features	Value	Rating class and limiting features	Value
Lu—Lumbee sandy loam					
Lumbee, drained	85	Very limited		Very limited	
		Filtering capacity	1.00	Filtering capacity	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Leaching	0.70	Too acid	1.00
		Too acid	0.68	Flooding	0.40
		Strongly contrasting textural stratification	0.06	Strongly contrasting textural stratification	0.06
Lumbee, undrained	15	Very limited		Very limited	
		Filtering capacity	1.00	Filtering capacity	1.00
		Ponding	1.00	Ponding	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Leaching	0.70	Too acid	1.00
		Too acid	0.68	Flooding	0.40
Ly—Lynchburg sandy loam					
Lynchburg, drained	90	Very limited		Very limited	
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Leaching	0.90	Too acid	1.00
		Too acid	0.68		
		Low adsorption	0.02		
Lynchburg, undrained	4	Very limited		Very limited	
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Leaching	0.90	Too acid	1.00
		Too acid	0.68		
		Low adsorption	0.02		
MaA—Marlboro sandy loam, 0 to 2 percent slopes					
Marlboro	90	Somewhat limited		Somewhat limited	
		Low adsorption	0.39	Too acid	0.42
		Too acid	0.11		
MaB—Marlboro sandy loam, 2 to 6 percent slopes					
Marlboro	90	Somewhat limited		Somewhat limited	
		Low adsorption	0.39	Too acid	0.42
		Too acid	0.11		

Agricultural Disposal of Manure, Food-Processing Waste, and Sewage Sludge–Robeson County, North Carolina					
Map symbol and soil name	Pct. of map unit	Application of manure and food-processing waste		Application of sewage sludge	
		Rating class and limiting features	Value	Rating class and limiting features	Value
Mc—McColl loam					
Mccoll, ponded	80	Very limited		Very limited	
		Slow water movement	1.00	Ponding	1.00
		Ponding	1.00	Depth to saturated zone	1.00
		Depth to saturated zone	1.00	Slow water movement	1.00
		Dense layer	1.00	Too acid	0.31
		Runoff	0.40		
Mccoll, drained	10	Very limited		Very limited	
		Slow water movement	1.00	Depth to saturated zone	1.00
		Depth to saturated zone	1.00	Slow water movement	1.00
		Dense layer	1.00	Too acid	0.31
		Runoff	0.40		
		Too acid	0.08		
NoA—Norfolk loamy sand, 0 to 2 percent slopes					
Norfolk	85	Somewhat limited		Very limited	
		Too acid	0.62	Too acid	1.00
		Leaching	0.45		
NoB—Norfolk loamy sand, 2 to 6 percent slopes					
Norfolk	85	Somewhat limited		Very limited	
		Too acid	0.62	Too acid	1.00
		Leaching	0.45		
NsC—Norfolk and Faceville soils, 6 to 10 percent slopes					
Norfolk	40	Somewhat limited		Very limited	
		Too acid	0.62	Too acid	1.00
		Leaching	0.45		
Faceville	30	Somewhat limited		Somewhat limited	
		Too acid	0.22	Too acid	0.77
		Low adsorption	0.17		
Pa—Pactolus loamy sand					
Pactolus	90	Very limited		Very limited	
		Filtering capacity	1.00	Filtering capacity	1.00
		Depth to saturated zone	0.99	Too acid	1.00
		Too acid	0.78	Depth to saturated zone	0.99
		Leaching	0.45	Flooding	0.40
		Droughty	0.11	Droughty	0.11

Custom Soil Resource Report

Agricultural Disposal of Manure, Food-Processing Waste, and Sewage Sludge–Robeson County, North Carolina					
Map symbol and soil name	Pct. of map unit	Application of manure and food-processing waste		Application of sewage sludge	
		Rating class and limiting features	Value	Rating class and limiting features	Value
Pg—Pantego fine sandy loam					
Pantego, drained	80	Very limited		Very limited	
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Too acid	0.78	Too acid	1.00
		Leaching	0.70	Flooding	0.40
Pantego, undrained	10	Very limited		Very limited	
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Too acid	0.78	Too acid	1.00
		Leaching	0.70	Flooding	0.40
Pm—Plummer and Osier soils					
Plummer, undrained	40	Very limited		Very limited	
		Filtering capacity	1.00	Filtering capacity	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Leaching	0.90	Too acid	1.00
		Too acid	0.73	Flooding	0.20
Osier, undrained	30	Very limited		Very limited	
		Filtering capacity	1.00	Filtering capacity	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Flooding	1.00	Flooding	1.00
		Leaching	0.90	Too acid	1.00
		Too acid	0.62	Droughty	0.37
PoB—Pocalla loamy sand, 0 to 3 percent slopes					
Pocalla	90	Very limited		Very limited	
		Filtering capacity	1.00	Filtering capacity	1.00
		Leaching	0.45	Too acid	0.77
		Low adsorption	0.23	Depth to saturated zone	0.18
		Too acid	0.22		
		Depth to saturated zone	0.18		

Custom Soil Resource Report

Agricultural Disposal of Manure, Food-Processing Waste, and Sewage Sludge–Robeson County, North Carolina					
Map symbol and soil name	Pct. of map unit	Application of manure and food-processing waste		Application of sewage sludge	
		Rating class and limiting features	Value	Rating class and limiting features	Value
Pr—Ponzer muck, siliceous subsoil variant (Croatan)					
Croatan, undrained	80	Very limited		Very limited	
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Too acid	1.00	Too acid	1.00
		Leaching	0.70	Flooding	0.40
Croatan, drained	10	Very limited		Very limited	
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Too acid	1.00	Too acid	1.00
		Leaching	0.70	Flooding	0.40
Pt—Portsmouth loam					
Portsmouth, drained	80	Very limited		Very limited	
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Too acid	0.78	Too acid	1.00
		Leaching	0.70	Flooding	0.40
		Strongly contrasting textural stratification	0.01	Strongly contrasting textural stratification	0.01
Portsmouth, undrained	10	Very limited		Very limited	
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Too acid	0.78	Too acid	1.00
		Leaching	0.70	Flooding	0.40
		Strongly contrasting textural stratification	0.01	Strongly contrasting textural stratification	0.01
Ra—Rains sandy loam					
Rains, drained	80	Very limited		Very limited	
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Leaching	0.70	Too acid	0.99
		Too acid	0.43		
Rains, undrained	10	Very limited		Very limited	
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Leaching	0.70	Too acid	0.99
		Too acid	0.43		

Custom Soil Resource Report

Agricultural Disposal of Manure, Food-Processing Waste, and Sewage Sludge–Robeson County, North Carolina					
Map symbol and soil name	Pct. of map unit	Application of manure and food-processing waste		Application of sewage sludge	
		Rating class and limiting features	Value	Rating class and limiting features	Value
Ru—Rutlege loamy sand					
Rutlege, undrained	80	Very limited		Very limited	
		Filtering capacity	1.00	Filtering capacity	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Leaching	0.90	Too acid	1.00
		Too acid	0.73	Flooding	0.40
		Droughty	0.01	Droughty	0.01
Rutlege, drained	10	Very limited		Very limited	
		Filtering capacity	1.00	Filtering capacity	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Leaching	0.90	Too acid	1.00
		Too acid	0.73	Flooding	0.40
		Droughty	0.01	Droughty	0.01
Ta—Toisnot loam					
Toisnot, undrained	80	Very limited		Very limited	
		Slow water movement	1.00	Ponding	1.00
		Ponding	1.00	Depth to saturated zone	1.00
		Depth to saturated zone	1.00	Slow water movement	1.00
		Leaching	0.50	Too acid	1.00
		Too acid	0.50		
Toisnot, drained	10	Very limited		Very limited	
		Slow water movement	1.00	Depth to saturated zone	1.00
		Depth to saturated zone	1.00	Slow water movement	1.00
		Leaching	0.50	Too acid	1.00
		Too acid	0.50		
To—Torhunta loam					
Torhunta, drained	80	Very limited		Very limited	
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Leaching	0.90	Too acid	1.00
		Too acid	0.78		
Torhunta, undrained	10	Very limited		Very limited	
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Leaching	0.90	Too acid	1.00
		Too acid	0.78		

Agricultural Disposal of Manure, Food-Processing Waste, and Sewage Sludge–Robeson County, North Carolina					
Map symbol and soil name	Pct. of map unit	Application of manure and food-processing waste		Application of sewage sludge	
		Rating class and limiting features	Value	Rating class and limiting features	Value
Ud—Udorthents, loamy					
Udorthents	100	Somewhat limited		Somewhat limited	
		Too acid	0.32	Too acid	0.92
		Low adsorption	0.30	Low adsorption	0.30
W—Water					
Water	100	Not rated		Not rated	
WaB—Wagram loamy sand, 0 to 6 percent slopes					
Wagram	90	Very limited		Very limited	
		Filtering capacity	1.00	Filtering capacity	1.00
		Leaching	0.45	Too acid	0.92
		Too acid	0.32		
WaC—Wagram loamy sand, 6 to 10 percent slopes					
Wagram	85	Very limited		Very limited	
		Filtering capacity	1.00	Filtering capacity	1.00
		Leaching	0.45	Too acid	0.92
		Too acid	0.32		
WkB—Wakulla sand, 0 to 6 percent slopes					
Wakulla	90	Very limited		Very limited	
		Filtering capacity	1.00	Filtering capacity	1.00
		Droughty	0.94	Droughty	0.94
		Leaching	0.45	Too acid	0.92
		Too acid	0.32		

Agricultural Disposal of Wastewater by Irrigation and Overland Flow

Soil properties are important considerations in areas where soils are used as sites for the treatment and disposal of organic waste and wastewater. Selection of soils with properties that favor waste management can help to prevent environmental damage.

This table shows the degree and kind of soil limitations affecting the treatment of wastewater, including municipal and food-processing wastewater and effluent from lagoons or storage ponds. Municipal wastewater is the waste stream from a municipality. It contains domestic waste and may contain industrial waste. It may have received primary or secondary treatment. It is rarely untreated sewage. Food-processing wastewater results from the preparation of fruits, vegetables, milk, cheese, and meats for public consumption. In places it is high in content of sodium and chloride.

In the context of this table, the effluent in lagoons and storage ponds is from facilities used to treat or store food-processing wastewater or domestic or animal waste. Domestic and food-processing wastewater is very dilute, and the effluent from the facilities that treat or store it commonly is very low in content of carbonaceous and nitrogenous material; the content of nitrogen commonly ranges from 10 to 30 milligrams per liter. The wastewater from animal waste treatment lagoons or storage ponds, however, has much higher concentrations of these materials, mainly because the manure has not been diluted as much as the domestic waste. The content of nitrogen in this wastewater generally ranges from 50 to 2,000 milligrams per liter. When wastewater is applied, checks should be made to ensure that nitrogen, heavy metals, and salts are not added in excessive amounts.

The ratings in the table are for waste management systems that not only dispose of and treat wastewater but also are beneficial to crops. The ratings are both verbal and numerical. Rating class terms indicate the extent to which the soils are limited by all of the soil features that affect agricultural waste management. *Not limited* indicates that the soil has features that are very favorable for the specified use. Good performance and very low maintenance can be expected. *Somewhat limited* indicates that the soil has features that are moderately favorable for the specified use. The limitations can be overcome or minimized by special planning, design, or installation. Fair performance and moderate maintenance can be expected. *Very limited* indicates that the soil has one or more features that are unfavorable for the specified use. The limitations generally cannot be overcome without major soil reclamation, special design, or expensive installation procedures. Poor performance and high maintenance can be expected.

Numerical ratings in the tables indicate the severity of individual limitations. The ratings are shown as decimal fractions ranging from 0.01 to 1.00. They indicate gradations between the point at which a soil feature has the greatest negative impact on the use (1.00) and the point at which the soil feature is not a limitation (0.00).

Disposal of wastewater by irrigation not only disposes of municipal wastewater and wastewater from food-processing plants, lagoons, and storage ponds but also can improve crop production by increasing the amount of water available to crops. The ratings in the table are based on the soil properties that affect the design, construction, management, and performance of the irrigation system. The properties that affect design and management include the sodium adsorption ratio, depth to a water table, ponding, available water capacity, Ksat, slope, and flooding. The properties that affect construction include stones, cobbles, depth to bedrock or a cemented pan, depth to a water table, and ponding. The properties that affect performance include depth to bedrock or a cemented pan, bulk density, the sodium adsorption ratio, salinity, reaction, and the cation-exchange capacity, which is used to estimate the capacity of a soil to adsorb heavy metals. Permanently frozen soils are not suitable for disposal of wastewater by irrigation.

Overland flow of wastewater is a process in which wastewater is applied to the upper reaches of sloped land and allowed to flow across vegetated surfaces, sometimes called terraces, to runoff-collection ditches. The length of the run generally is 150 to 300 feet. The application rate ranges from 2.5 to 16.0 inches per week. It commonly exceeds the rate needed for irrigation of cropland. The wastewater leaves solids and nutrients on the vegetated surfaces as it flows downslope in a thin film. Most of the water reaches the collection ditch, some is lost through evapotranspiration, and a small amount may percolate to the ground water.

The ratings in the table are based on the soil properties that affect absorption, plant growth, microbial activity, and the design and construction of the system. Reaction and the cation-exchange capacity affect absorption. Reaction, salinity, and the sodium adsorption ratio affect plant growth and microbial activity. Slope, saturated hydraulic conductivity (Ksat), depth to a water table, ponding, flooding, depth to bedrock or a cemented pan, stones, and cobbles affect design and construction. Permanently frozen soils are unsuitable for waste treatment.

Report—Agricultural Disposal of Wastewater by Irrigation and Overland Flow

[Onsite investigation may be needed to validate the interpretations in this table and to confirm the identity of the soil on a given site. The numbers in the value columns range from 0.01 to 1.00. The larger the value, the greater the potential limitation. The table shows only the top five limitations for any given soil. The soil may have additional limitations]

Agricultural Disposal of Wastewater by Irrigation and Overland Flow–Cumberland County, North Carolina					
Map symbol and soil name	Pct. of map unit	Disposal of wastewater by irrigation		Overland flow of wastewater	
		Rating class and limiting features	Value	Rating class and limiting features	Value
AuA—Autryville loamy sand, 0 to 2 percent slopes					
Autryville	90	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Too acid	0.77	Too acid	0.77
CaB—Candor sand, 1 to 8 percent slopes					
Candor	80	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Too acid	1.00	Too acid	1.00
		Too steep for surface application	0.32		
		Droughty	0.04		
GoA—Goldsboro loamy sand, 0 to 2 percent slopes					
Goldsboro	90	Very limited		Very limited	
		Too acid	1.00	Seepage	1.00
		Depth to saturated zone	0.99	Too acid	1.00
		Low adsorption	0.01	Depth to saturated zone	0.99
				Low adsorption	0.01

Agricultural Disposal of Wastewater by Irrigation and Overland Flow–Cumberland County, North Carolina					
Map symbol and soil name	Pct. of map unit	Disposal of wastewater by irrigation		Overland flow of wastewater	
		Rating class and limiting features	Value	Rating class and limiting features	Value
JT—Johnston loam					
Johnston, undrained	85	Very limited		Very limited	
		Ponding	1.00	Seepage	1.00
		Depth to saturated zone	1.00	Ponding	1.00
		Flooding	1.00	Depth to saturated zone	1.00
		Too acid	1.00	Flooding	1.00
				Too acid	1.00
Johnston, drained	15	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Ponding	1.00	Ponding	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Flooding	1.00	Flooding	1.00
		Too acid	1.00	Too acid	1.00
Pa—Pactolus loamy sand					
Pactolus	90	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Too acid	1.00	Too acid	1.00
		Depth to saturated zone	0.99	Depth to saturated zone	0.99
		Droughty	0.11		
WaB—Wagram loamy sand, 0 to 6 percent slopes					
Wagram	90	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Too acid	0.92	Too acid	0.92

Agricultural Disposal of Wastewater by Irrigation and Overland Flow–Robeson County, North Carolina					
Map symbol and soil name	Pct. of map unit	Disposal of wastewater by irrigation		Overland flow of wastewater	
		Rating class and limiting features	Value	Rating class and limiting features	Value
BB—Bibb soils					
Bibb, undrained	80	Very limited		Very limited	
		Depth to saturated zone	1.00	Seepage	1.00
		Flooding	1.00	Depth to saturated zone	1.00
		Too acid	1.00	Flooding	1.00
				Too acid	1.00
Johnston, undrained	10	Very limited		Very limited	
		Ponding	1.00	Seepage	1.00
		Depth to saturated zone	1.00	Ponding	1.00
		Flooding	1.00	Depth to saturated zone	1.00
		Too acid	1.00	Flooding	1.00
				Too acid	1.00
Bp—Borrow pit					
Pits, sand	100	Not rated		Not rated	
By—Byars loam					
Byars, ponded	80	Very limited		Very limited	
		Ponding	1.00	Seepage	1.00
		Depth to saturated zone	1.00	Ponding	1.00
		Slow water movement	1.00	Depth to saturated zone	1.00
		Too acid	1.00	Too acid	1.00
		Low adsorption	0.04	Low adsorption	0.04
Byars, drained	10	Very limited		Very limited	
		Depth to saturated zone	1.00	Seepage	1.00
		Slow water movement	1.00	Depth to saturated zone	1.00
		Too acid	1.00	Too acid	1.00
		Low adsorption	0.04	Low adsorption	0.04
Co—Coxville loam					
Coxville, drained	85	Very limited		Very limited	
		Depth to saturated zone	1.00	Seepage	1.00
		Too acid	1.00	Depth to saturated zone	1.00
		Low adsorption	0.65	Too acid	1.00
		Slow water movement	0.22	Low adsorption	0.65
Coxville, undrained	10	Very limited		Very limited	
		Depth to saturated zone	1.00	Seepage	1.00
		Too acid	1.00	Depth to saturated zone	1.00
		Low adsorption	0.65	Too acid	1.00
		Slow water movement	0.22	Low adsorption	0.65

Agricultural Disposal of Wastewater by Irrigation and Overland Flow–Robeson County, North Carolina					
Map symbol and soil name	Pct. of map unit	Disposal of wastewater by irrigation		Overland flow of wastewater	
		Rating class and limiting features	Value	Rating class and limiting features	Value
Dn—Dunbar sandy loam					
Dunbar, drained	80	Very limited		Very limited	
		Depth to saturated zone	1.00	Seepage	1.00
		Too acid	1.00	Depth to saturated zone	1.00
		Slow water movement	0.22	Too acid	1.00
		Low adsorption	0.20	Low adsorption	0.20
Dunbar, undrained	10	Very limited		Very limited	
		Depth to saturated zone	1.00	Seepage	1.00
		Too acid	1.00	Depth to saturated zone	1.00
		Slow water movement	0.22	Too acid	1.00
		Low adsorption	0.20	Low adsorption	0.20
DpA—Duplin sandy loam, 0 to 2 percent slopes					
Duplin	85	Somewhat limited		Very limited	
		Depth to saturated zone	0.99	Seepage	1.00
		Low adsorption	0.42	Depth to saturated zone	0.99
		Slow water movement	0.22	Low adsorption	0.42
		Too acid	0.21	Too acid	0.21
DpB—Duplin sandy loam, 2 to 6 percent slopes					
Duplin	90	Somewhat limited		Very limited	
		Depth to saturated zone	0.99	Seepage	1.00
		Low adsorption	0.42	Depth to saturated zone	0.99
		Slow water movement	0.22	Low adsorption	0.42
		Too steep for surface application	0.08	Too acid	0.08
		Too acid	0.08		
FaB—Faceville fine sandy loam, 2 to 6 percent slopes					
Faceville	85	Somewhat limited		Very limited	
		Too acid	0.77	Seepage	1.00
		Low adsorption	0.17	Too acid	0.77
		Too steep for surface application	0.08	Low adsorption	0.17

Agricultural Disposal of Wastewater by Irrigation and Overland Flow–Robeson County, North Carolina					
Map symbol and soil name	Pct. of map unit	Disposal of wastewater by irrigation		Overland flow of wastewater	
		Rating class and limiting features	Value	Rating class and limiting features	Value
GoA—Goldsboro loamy sand, 0 to 2 percent slopes					
Goldsboro	90	Very limited		Very limited	
		Too acid	1.00	Seepage	1.00
		Depth to saturated zone	0.99	Too acid	1.00
		Low adsorption	0.01	Depth to saturated zone	0.99
				Low adsorption	0.01
Jo—Johns sandy loam					
Johns	85	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Too acid	1.00	Too acid	1.00
		Depth to saturated zone	0.99	Depth to saturated zone	0.99
		Low adsorption	0.02	Flooding	0.40
				Low adsorption	0.02
JT—Johnston soils					
Johnston, undrained	85	Very limited		Very limited	
		Ponding	1.00	Seepage	1.00
		Depth to saturated zone	1.00	Ponding	1.00
		Flooding	1.00	Depth to saturated zone	1.00
		Too acid	1.00	Flooding	1.00
				Too acid	1.00
Johnston, drained	15	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Ponding	1.00	Ponding	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Flooding	1.00	Flooding	1.00
		Too acid	1.00	Too acid	1.00
KaA—Kalmia loamy sand, 0 to 2 percent slopes					
Kalmia	85	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Too acid	1.00	Too acid	1.00
		Low adsorption	0.12	Flooding	0.40
				Low adsorption	0.12

Custom Soil Resource Report

Agricultural Disposal of Wastewater by Irrigation and Overland Flow–Robeson County, North Carolina					
Map symbol and soil name	Pct. of map unit	Disposal of wastewater by irrigation		Overland flow of wastewater	
		Rating class and limiting features	Value	Rating class and limiting features	Value
LaB—Lakeland sand, 0 to 6 percent slopes					
Lakeland	80	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Too acid	0.92	Too acid	0.92
		Droughty	0.21		
Le—Leon sand					
Leon	80	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Too acid	0.99	Too acid	0.99
		Droughty	0.14		
Lu—Lumbee sandy loam					
Lumbee, drained	85	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Too acid	1.00	Too acid	1.00
				Flooding	0.40
Lumbee, undrained	15	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Ponding	1.00	Ponding	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Too acid	1.00	Too acid	1.00
				Flooding	0.40
Ly—Lynchburg sandy loam					
Lynchburg, drained	90	Very limited		Very limited	
		Depth to saturated zone	1.00	Seepage	1.00
		Too acid	1.00	Depth to saturated zone	1.00
		Low adsorption	0.02	Too acid	1.00
				Low adsorption	0.02
Lynchburg, undrained	4	Very limited		Very limited	
		Depth to saturated zone	1.00	Seepage	1.00
		Too acid	1.00	Depth to saturated zone	1.00
		Low adsorption	0.02	Too acid	1.00
				Low adsorption	0.02

Agricultural Disposal of Wastewater by Irrigation and Overland Flow–Robeson County, North Carolina					
Map symbol and soil name	Pct. of map unit	Disposal of wastewater by irrigation		Overland flow of wastewater	
		Rating class and limiting features	Value	Rating class and limiting features	Value
MaA—Marlboro sandy loam, 0 to 2 percent slopes					
Marlboro	90	Somewhat limited		Very limited	
		Too acid	0.42	Seepage	1.00
		Low adsorption	0.39	Too acid	0.42
				Low adsorption	0.39
MaB—Marlboro sandy loam, 2 to 6 percent slopes					
Marlboro	90	Somewhat limited		Very limited	
		Too acid	0.42	Seepage	1.00
		Low adsorption	0.39	Too acid	0.42
		Too steep for surface application	0.08	Low adsorption	0.39
Mc—McColl loam					
Mccoll, ponded	80	Very limited		Very limited	
		Ponding	1.00	Seepage	1.00
		Depth to saturated zone	1.00	Ponding	1.00
		Slow water movement	1.00	Depth to saturated zone	1.00
		Too acid	0.31	Too acid	0.31
Mccoll, drained	10	Very limited		Very limited	
		Depth to saturated zone	1.00	Seepage	1.00
		Slow water movement	1.00	Depth to saturated zone	1.00
		Too acid	0.31	Too acid	0.31
NoA—Norfolk loamy sand, 0 to 2 percent slopes					
Norfolk	85	Very limited		Very limited	
		Too acid	1.00	Seepage	1.00
				Too acid	1.00
NoB—Norfolk loamy sand, 2 to 6 percent slopes					
Norfolk	85	Very limited		Very limited	
		Too acid	1.00	Seepage	1.00
		Too steep for surface application	0.08	Too acid	1.00

Agricultural Disposal of Wastewater by Irrigation and Overland Flow–Robeson County, North Carolina					
Map symbol and soil name	Pct. of map unit	Disposal of wastewater by irrigation		Overland flow of wastewater	
		Rating class and limiting features	Value	Rating class and limiting features	Value
NsC—Norfolk and Faceville soils, 6 to 10 percent slopes					
Norfolk	40	Very limited		Very limited	
		Too steep for surface application	1.00	Seepage	1.00
		Too acid	1.00	Too acid	1.00
		Too steep for sprinkler application	0.10	Too steep for surface application	0.22
Faceville	30	Very limited		Very limited	
		Too steep for surface application	1.00	Seepage	1.00
		Too acid	0.77	Too acid	0.77
		Low adsorption	0.17	Too steep for surface application	0.22
		Too steep for sprinkler application	0.10	Low adsorption	0.17
Pa—Pactolus loamy sand					
Pactolus	90	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Too acid	1.00	Too acid	1.00
		Depth to saturated zone	0.99	Depth to saturated zone	0.99
		Droughty	0.11	Flooding	0.40
Pg—Pantego fine sandy loam					
Pantego, drained	80	Very limited		Very limited	
		Depth to saturated zone	1.00	Seepage	1.00
		Too acid	1.00	Depth to saturated zone	1.00
				Too acid	1.00
				Flooding	0.40
Pantego, undrained	10	Very limited		Very limited	
		Depth to saturated zone	1.00	Seepage	1.00
		Too acid	1.00	Depth to saturated zone	1.00
				Too acid	1.00
				Flooding	0.40

Custom Soil Resource Report

Agricultural Disposal of Wastewater by Irrigation and Overland Flow–Robeson County, North Carolina					
Map symbol and soil name	Pct. of map unit	Disposal of wastewater by irrigation		Overland flow of wastewater	
		Rating class and limiting features	Value	Rating class and limiting features	Value
Pm—Plummer and Osier soils					
Plummer, undrained	40	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Too acid	1.00	Too acid	1.00
				Flooding	0.20
Osier, undrained	30	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Flooding	1.00	Flooding	1.00
		Too acid	1.00	Too acid	1.00
		Droughty	0.37		
PoB—Pocalla loamy sand, 0 to 3 percent slopes					
Pocalla	90	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Too acid	0.77	Too acid	0.77
		Low adsorption	0.23	Low adsorption	0.23
		Depth to saturated zone	0.18	Depth to saturated zone	0.18
Pr—Ponzer muck, siliceous subsoil variant (Croatan)					
Croatan, undrained	80	Very limited		Very limited	
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Too acid	1.00	Too acid	1.00
				Seepage	1.00
				Flooding	0.40
Croatan, drained	10	Very limited		Very limited	
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Too acid	1.00	Too acid	1.00
				Seepage	1.00
				Flooding	0.40

Agricultural Disposal of Wastewater by Irrigation and Overland Flow–Robeson County, North Carolina					
Map symbol and soil name	Pct. of map unit	Disposal of wastewater by irrigation		Overland flow of wastewater	
		Rating class and limiting features	Value	Rating class and limiting features	Value
Pt—Portsmouth loam					
Portsmouth, drained	80	Very limited		Very limited	
		Depth to saturated zone	1.00	Seepage	1.00
		Too acid	1.00	Depth to saturated zone	1.00
				Too acid	1.00
				Flooding	0.40
Portsmouth, undrained	10	Very limited		Very limited	
		Depth to saturated zone	1.00	Seepage	1.00
		Too acid	1.00	Depth to saturated zone	1.00
				Too acid	1.00
				Flooding	0.40
Ra—Rains sandy loam					
Rains, drained	80	Very limited		Very limited	
		Depth to saturated zone	1.00	Seepage	1.00
		Too acid	0.99	Depth to saturated zone	1.00
				Too acid	0.99
Rains, undrained	10	Very limited		Very limited	
		Depth to saturated zone	1.00	Seepage	1.00
		Too acid	0.99	Depth to saturated zone	1.00
				Too acid	0.99
Ru—Rutlege loamy sand					
Rutlege, undrained	80	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Too acid	1.00	Too acid	1.00
		Droughty	0.01	Flooding	0.40
Rutlege, drained	10	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Depth to saturated zone	1.00	Depth to saturated zone	1.00
		Too acid	1.00	Too acid	1.00
		Droughty	0.01	Flooding	0.40

Agricultural Disposal of Wastewater by Irrigation and Overland Flow–Robeson County, North Carolina					
Map symbol and soil name	Pct. of map unit	Disposal of wastewater by irrigation		Overland flow of wastewater	
		Rating class and limiting features	Value	Rating class and limiting features	Value
Ta—Toisnot loam					
Toisnot, undrained	80	Very limited		Very limited	
		Ponding	1.00	Seepage	1.00
		Depth to saturated zone	1.00	Ponding	1.00
		Slow water movement	1.00	Depth to saturated zone	1.00
		Too acid	1.00	Too acid	1.00
Toisnot, drained	10	Very limited		Very limited	
		Depth to saturated zone	1.00	Seepage	1.00
		Slow water movement	1.00	Depth to saturated zone	1.00
		Too acid	1.00	Too acid	1.00
To—Torhunta loam					
Torhunta, drained	80	Very limited		Very limited	
		Depth to saturated zone	1.00	Seepage	1.00
		Too acid	1.00	Depth to saturated zone	1.00
				Too acid	1.00
Torhunta, undrained	10	Very limited		Very limited	
		Depth to saturated zone	1.00	Seepage	1.00
		Too acid	1.00	Depth to saturated zone	1.00
				Too acid	1.00
Ud—Udorthents, loamy					
Udorthents	100	Somewhat limited		Very limited	
		Too acid	0.92	Seepage	1.00
		Low adsorption	0.30	Too acid	0.92
				Low adsorption	0.30
W—Water					
Water	100	Not rated		Not rated	
WaB—Wagram loamy sand, 0 to 6 percent slopes					
Wagram	90	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Too acid	0.92	Too acid	0.92

Agricultural Disposal of Wastewater by Irrigation and Overland Flow–Robeson County, North Carolina					
Map symbol and soil name	Pct. of map unit	Disposal of wastewater by irrigation		Overland flow of wastewater	
		Rating class and limiting features	Value	Rating class and limiting features	Value
WaC—Wagram loamy sand, 6 to 10 percent slopes					
Wagram	85	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Too steep for surface application	1.00	Too acid	0.92
		Too acid	0.92	Too steep for surface application	0.22
		Too steep for sprinkler application	0.10		
WkB—Wakulla sand, 0 to 6 percent slopes					
Wakulla	90	Very limited		Very limited	
		Filtering capacity	1.00	Seepage	1.00
		Droughty	0.94	Too acid	0.92
		Too acid	0.92		

References

American Association of State Highway and Transportation Officials (AASHTO). 2004. Standard specifications for transportation materials and methods of sampling and testing. 24th edition.

American Society for Testing and Materials (ASTM). 2005. Standard classification of soils for engineering purposes. ASTM Standard D2487-00.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deep-water habitats of the United States. U.S. Fish and Wildlife Service FWS/OBS-79/31.

Federal Register. July 13, 1994. Changes in hydric soils of the United States.

Federal Register. September 18, 2002. Hydric soils of the United States.

Hurt, G.W., and L.M. Vasilas, editors. Version 6.0, 2006. Field indicators of hydric soils in the United States.

National Research Council. 1995. Wetlands: Characteristics and boundaries.

Soil Survey Division Staff. 1993. Soil survey manual. Soil Conservation Service. U.S. Department of Agriculture Handbook 18. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/soils/?cid=nrcs142p2_054262

Soil Survey Staff. 1999. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. 2nd edition. Natural Resources Conservation Service, U.S. Department of Agriculture Handbook 436. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/soils/?cid=nrcs142p2_053577

Soil Survey Staff. 2010. Keys to soil taxonomy. 11th edition. U.S. Department of Agriculture, Natural Resources Conservation Service. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/soils/?cid=nrcs142p2_053580

Tiner, R.W., Jr. 1985. Wetlands of Delaware. U.S. Fish and Wildlife Service and Delaware Department of Natural Resources and Environmental Control, Wetlands Section.

United States Army Corps of Engineers, Environmental Laboratory. 1987. Corps of Engineers wetlands delineation manual. Waterways Experiment Station Technical Report Y-87-1.

United States Department of Agriculture, Natural Resources Conservation Service. National forestry manual. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/home/?cid=nrcs142p2_053374

United States Department of Agriculture, Natural Resources Conservation Service. National range and pasture handbook. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/landuse/rangepasture/?cid=stelprdb1043084

United States Department of Agriculture, Natural Resources Conservation Service. National soil survey handbook, title 430-VI. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/scientists/?cid=nrcs142p2_054242

United States Department of Agriculture, Natural Resources Conservation Service. 2006. Land resource regions and major land resource areas of the United States, the Caribbean, and the Pacific Basin. U.S. Department of Agriculture Handbook 296. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/soils/?cid=nrcs142p2_053624

United States Department of Agriculture, Soil Conservation Service. 1961. Land capability classification. U.S. Department of Agriculture Handbook 210. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_052290.pdf

Thornburg, Nathaniel

From:	mac cca <mac_cca@bellsouth.net>
Sent:	Friday, October 02, 2015 4:26 PM
To:	Thornburg, Nathaniel
Subject:	Letter of Comment - Sanderson Farms Permit Proposal
Attachments:	Letter to DENR - Sanderson Farms Permit Proposal.docx
Follow Up Flag:	Follow up
Flag Status:	Flagged
Categories:	Important

Please see attached letter.

Kindly,

Rev. Mac Legerton

October 2. 2015

Nathaniel Thornburg
Division of Water Resources
Water Quality Permitting Section
Non-Discharge Permitting Unit
1617 Mail Service Center
Raleigh, NC 27699-1617

Subject: Draft Permit WQ0037772 - Sanderson Farms

Dear Mr.Thornburg:

I am writing to provide an evaluation and recommendation on the draft water quality permit of Sanderson Farms and water quality issues related to the siting of the proposed location at this site and in Robeson County, N.C.

First, I would like to describe particulars of my own professional experience and expertise that are the resource with which I developed the following evaluation and recommendation. I have been engaged in the field of environmental protection and promotion for 42 years, beginning with internship experience in the Delaware Water Gap region of Pennsylvania. I have been directly involved in environmental protection and promotion work in Robeson County for 35 years, serving as Executive Director of the Center for Community Action. I come to the work with formal training in:
(1) qualitative and quantitative research through doctoral level studies at Columbia University Teachers College; and (2) ethical and educational studies in this field through the Masters of Arts in Education and Theological Studies at Union Theological Seminary in New York. I'm an ordained minister in the United Church of Christ in service of community ministry and in the new and growing field of eco-ministry.

Of equal importance to my formal training in environmental protection and promotion is my experience, practice, and understanding of the field. Since 1984, I have been engaged in extensive in this field of work in Robeson County. Our county and region have been sited for many massive landfills, hazardous and toxic waste, and low-level radioactive waste facilities. None of the proposed, massive projects were sited in our county and region for many of the same indicators that I have documented in this letter to you. These include:

(1) the proposal of U.S. Ecology to build a low-level, radioactive incinerator in Bladen County;
(2) the proposal of GSX to build large, hazardous waste treatment facility in Scotland County and discharge into the Lumber River in Robeson County;
(3) the proposal of Waste Management to build a multi-state, low-level radioactive waste landfill in Richmond County;

(4) the proposal of Waste Management to build a regional solid waste landfill in Columbus County; and
(5) a proposal to incinerate large amounts of discarded tires in Robeson County.

While all of these proposals raised significant risks to the land, water, and air in our region, they also were not suitable due to their scale of operations and corporate experience or lack of experience in the planned methods of operations. Their unsuitability was only exacerbated by the vulnerabilities of our region due to our eco-system, geography, and population. I will discuss all of these factors in relation to the draft water quality permit of Sanderson Farms as well. The following paragraphs include details related to these all of these factors in the context of the draft water quality permit that DENR has issued to Sanderson Farms.

Although Sanderson Farms filed test results and a report stating the identification of 350 acres of land near St.Pauls, N.C. that meet the State requirements for spray field suitability and take into account rainfall, the proposed site includes and is adjacent two three swamps. All three swamps are located on and contiguous to the Sanderson Farms site. Sanderson Farms also proposes a holding pond for wastewater for purposes that include the inability to discharge it onto the spray fields due to unsuitable weather and soil conditions. Sanderson Farms is asking for a non-discharge permit in which the major responsibility for insuring conformity to such a permit is based on self-monitoring and self-reporting. Further, Sanderson Farms has not proposed, nor has Robeson County or DENR officials required, any restrictions on pollutants that will be applied to the land that is directly alongside three swamps and surrounds major parts of two of them. Additionally, the majority of rainfall in Robeson County occurs in the winter season. During this season, there are usually multiple days and weeks in which it rains every single day, saturating the sandy, loamy soil and raising the water levels of surface and ground water that flow into the swamps and the Lumber River, causing them to swell. In the summer and fall, combinations of tropical fronts, storms, and hurricanes are a constant threat, removing the barriers between water and land to disappear as with winter rains. This causes major runoff of water into the streams, swamps, and river and major flooding of land by these same water sources. No land that is adjacent to our swamps and river in Robeson County are, or can be, protected from this natural and routine occurrence. No one that has lived in and knows Robeson County for any period of time will contest this fact.

These are just a few of the details related to the procedures and environment in which Sanderson Farms proposes, and the draft water quality permits, Sanderson Farms to discharge up to 1.4 million gallons of waste water and unrestricted amounts of pollutants through land application directly beside three swamps, all of which combine to drain into the Lumber River. The scale at which Sanderson Farms proposes to discharge its waste into this environment and the procedures it has proposed to use will pollute both the land on which it operates and the swamps which are its next door neighbors. In actuality, Sanderson Farms could not have picked a worst site in Robeson County in relation to its harm to the environment other than placing it directly alongside and surrounding the Lumber River, as it is proposing to do with Gum, Black Branch, and Big Marsh Swamps.

Given the indisputable realities of the environmental vulnerabilities of the proposed site location, why did Sanderson Farms select this site? Given these vulnerabilities, why did not Sanderson Farms initiate a request to apply more environmentally safe methods such as obtaining a federal surface water permit and procedure in which pollutants would be restricted and better monitored in order to improve the protection of both ground and surface waters. Why has not such a permit been required by local or state officials? If Sanderson Farms truly had protection of the sited environment as a major priority, why would it not have chosen a more appropriate and complete permit process and application?

For these and additional reasons that I will also detail, a non-discharge, water quality permit, even with further restrictions, will not protect the environment and natural resources of this site, its surroundings, and that of Robeson County as a whole.
As many state officials repeat over and over again to the public regarding the permitting process, state regulations require that regulators can only just proposals and permit applications on their own merits. Given all of these factors, there are more than enough merits and legal reasons to deny the application for a water quality permit at this particular, and most vulnerable site, in Southeastern North Carolina.

There are many other factors that also support the decision to deny application of Sanderson Farms for a water quality permit at this particular site. Robeson County already has a significant quantity of meatpacking processing plants, chicken farms, and hog farms in the county. For the last four decades, the citizens of Robeson County have led the way in many successful efforts to protect and promote its natural resources and those in the regions. With the high rates of poverty in the region, our natural resources are the most important component for our infrastructure for the natural and human development of our county. At this point in our history, the major source of environmental pollution and threat in Robeson County is the meatpacking industry and facilities. This is mainly due to the lack of more appropriate regulation of its processing plants and farms. There has not been a major, comprehensive environmental assessment of the existing level of pollution and contamination by the existing processing plants and farms, either in Robeson County or our region. Neither the company, local officials, nor state regulators have required it. To place another massive facility of the scale proposed, particularly in the existing site location, without this information would be irresponsible and, based on interpretations of legislation, may be required by law. There is significant lack of information regarding the present status of the environment and the impact of the meatpacking industry in Robeson County and the region. There is also the lack of uncertainty regarding whether such an assessment is required. The existing number of processing plants and farms, this lack of information on their impact, and disagreements related to legislative interpretation are further reasons to deny the application of Sanderson Farms for a water quality permit by at this site location in Robeson County at this time.

Further significant reasons to deny the permit application are these:

1. Robeson County has just received the highest rating in the nation for counties at risk of natural disasters. It also has received the highest rating of any county in N.C. Realtytrac has just released its 2015 Natural Disaster Housing Risk Report that giver Robeson County a rating of 190, the highest measurement possible in the most endangered, high risk category. This is because of the county's risk of natural disasters of hurricanes, storms, and forest fires. As I referenced earlier, local residents of Robeson County are highly aware of these vulnerabilities which are not documentable when only looking at individual plots of land and testing the their individual soil capacity in this highly interdependent, water-based eco-system with 50 swamps and a major river running through it. See: http://www.realtytrac.com/news/realtytrac-reports/realtytrac-2015-u-s-natural-disaster-housing-risk-report/

2. Robeson County, because of its poor rural nature with the most ethnically diverse, population in the nation, has been and is vulnerable industrial proposals that will under-develop its economy rather than develop it. We have many, many responsible corporate partners here. But given the lack of regulations regarding many aspects of the meatpacking industry, it has become our largest polluter of our land, water, and air. Our diverse populations have grown in their awareness and appreciation for the environment and understand the environmental justice issues that have been raised throughout our region related to attempts to site massive hazardous and low-level nuclear waste facilities here. At the present time, we don't have the capacity to even monitor and protect our citizens from the risks that we now face. We need no further major risks of harm to our place and people before we, together, take stock of where we are and what we really need to move our county and region economically and environmentally forward.

3. Lastly, Sanderson Farms' record of compliance with even its surface water permits in other states is dismal. To assume that they will somehow be responsible at this site, with all of its environmental risks, under a much-less restrictive type of permit, places our place and our people at very high risk.

For all of these reasons, I recommend that DENR deny the permit of Sanderson Farms for a water quality permit at its selected site in St. Pauls, N.C.

Sincerely,

Rev. Mac Legerton
P.O. Box 9
Pembroke, NC 28372

Thornburg, Nathaniel

From: Ryan Emanuel <reemanue@ncsu.edu>
Sent: Friday, October 02, 2015 4:58 PM
To: Thornburg, Nathaniel
Subject: Draft Permit WQ0037772 - Sanderson Farms

Follow Up Flag: Follow up
Flag Status: Flagged

Categories: Important

Nathaniel Thornburg

Division of Water Resources

Water Quality Permitting Section

Non-Discharge Permitting Unit

1617 Mail Service Center

Raleigh, NC 27699-1617

Mr. Thornburg,

I am an associate professor of hydrology in the College of Natural Resources at NC State University. I was asked to review and comment on the draft permit for Sanderson Farms (permit number WQ0037772) by local citizens and a nonprofit organization (Winyah Rivers Foundation). I am writing to express my expert opinion, which should not be taken as an official opinion of NC State University. I would like to highlight several key issues with this permit.

In its current form, the draft permit lacks sufficient monitoring to ensure that surface and groundwater resources will be protected. In particular, the monitoring efforts for effluent, soils, and groundwater described in the permit are currently insufficient to meet Performance Standard 1: "(t)he subject non-discharge facilities shall be effectively maintained and operated at all times so there is no discharge to surface waters, nor any contravention of groundwater or surface water standards." I would like to propose the following recommendations as minimum criteria for monitoring the facility's impact on surface water and groundwater resources:

- Surface water flow and quality should be monitored on Big Marsh, both upstream and downstream of the proposed land application fields. Monitoring should begin prior to any permitted land application. Given that the proposed land application fields lie on both sides of Big Marsh, establishing upstream and downstream monitoring sites will be the clearest and most direct way to assess compliance with the surface water criteria of Performance Standard 1.

- Nitrogen and phosphorus concentration limits for the WWTP effluent should be specified in Attachment A and specified as application limits in Attachment B. Without these limits, we have no knowledge of nutrient loads applied to these soils. Nutrient inputs will be required to assess the effluent's impact on shallow groundwater and the nearby surface waters to which it is connected.

- As part of efforts to assess the effluent's impact on shallow groundwater and surface waters, the annual representative soils analysis should include nitrogen in addition to the other variables listed. Any metals (arsenic, etc.) used as additives in chicken feed should be added to the list of variables monitored in soils. Feces and additives associated with feed could be present in wastewater, and metals in particular can accumulate in irrigated soils.

- Three times per year is an insufficient sampling frequency for groundwater monitoring wells. These wells should be sampled at least monthly to account for seasonality in climate, nutrient uptake by cover crops, and variability in effluent quality.

- Groundwater levels should be monitored continuously using water level recorders. In the case of shallow groundwater (i.e., water table) wells, continuous monitoring data will help assess the frequency of ponding and saturation excess runoff resulting from precipitation and wastewater irrigation (which could total 3 mm per day). In the case of confined aquifer wells, continuous monitoring data will help measure the cone of depression surrounding Sanderson's proposed water supply wells. There are good reasons to monitor both shallow and deep groundwater, although the draft permit did not specify which.

These monitoring recommendations, and additional scrutiny by DWR in the form of a more thorough environmental assessment, are warranted based on multiple factors. First, the location of the proposed land application sites relative to Big Marsh and its tributaries suggests that surface water impacts are likely. Even in the absence of surface runoff, these highly conductive soils will facilitate hydrologic connectivity between land application sites and surface waters via the shallow subsurface. The proposed irrigation rates (approximately 3 mm/day) are more than double the natural precipitation rate in this area and will lead to increased hydraulic gradients between the application fields and nearby surface waters. Given these factors, irrigation will only serve to increase hydrologic connectivity between application fields and Big Marsh. With that in mind, it is critical that effluent, groundwater and surface waters are monitored closely to ensure compliance with Performance Standard 1. Additional scrutiny is also warranted given that other facilities owned by Sanderson Farms have histories of water quality violations. Unless additional monitoring requirements are put in place, I do not think that this draft permit provides DWR with sufficient information to ensure the quality of surface water and groundwater resources. Without further modification and assessment, I recommend that this permit be denied.

Kind regards,

Ryan E. Emanuel, Ph.D.

North Carolina State University

919-513-2511

ryan_emanuel@ncsu.edu

APPENDIX J

ARCHAEOLOGICAL SURVEY

CULTURAL AND HISTORIC RESOURCES REVIEW

A cultural and historic resources review request was submitted to the North Carolina State Historic Preservation Office (NCSHPO) on March 18, 2015 for the proposed Sanderson Farms complex (processing plant, wastewater treatment and wastewater irrigation system) in Robeson County. The NCSHPO response indicated several previously recorded archaeological sites on the properties and a high probability of archaeological features being present (Attachment A). Per the NCSHPO recommendations, New South Associates coordinated with John Mintz of NCSHPO to conduct an archaeological survey of areas that might be impacted on the proposed complex property. The survey was conducted April 20-24, 2015, and a review of the New South findings is presented in Attachment B. Findings are summarized below as stated in the attached review from New South:

New South investigated 15 survey areas totaling 430 acres for a proposed poultry plant irrigation sites. The survey identified six isolated finds (IF 1-IF 6), five new archaeological sites (FS 1-FS 5), and one previously known site (31RB524). All were historic or modern and contained secondary cultural deposits or surface features. None of the identified resources retained integrity. None exhibited the potential to provide important information on the historic use of the area. New South recommends that all six isolated finds and all six sites as not eligible to the NRHP under any of the four criteria. No further archaeological work is recommended for this project.

North Carolina Department of Cultural Resources
State Historic Preservation Office
Ramona M. Bartos, Administrator

Governor Pat McCrory
Secretary Susan Kluttz

Office of Archives and History
Deputy Secretary Kevin Cherry

April 7, 2015

Stephen Dockery
Nutter & Associates, Inc.
360 Hawthorne Lane
Athens, GA 30602-2152

Re: Develop Sanderson Farms Processing Site and Land Treatment Sites, City of Saint Pauls Industrial Site, Robeson County, ER 15-0646

Dear Mr. Dockery:

Thank you for transmitting the information concerning the above referenced document.

After reviewing the information provided and based on the physical location, we have determined that there are several previously recorded archaeological sites situated within the project area. There exists a high probability that archaeological features associated with past residents may be present in the project area. We recommend that if any earth moving activities are scheduled to take place, that a comprehensive archaeological survey be conducted by an experienced archaeologist to identify and evaluate the significance of any archaeological remains that may be damaged or destroyed by the proposed project. *Please note that our office now requests consultation with the Office of State Archaeology Environmental Review Archaeologist to discuss appropriate field methodology prior to the archaeological field investigation.*

If an archaeological field investigation is conducted, two copies of the resulting archaeological survey report, as well as one copy of the appropriate site forms should be forwarded to us for review and comment as soon as they are available and well in advance of any earth moving activities.

We have determined that the project as proposed will not have an effect on any historic structures.

The above comments are made pursuant to Section 106 of the National Historic Preservation Act and the Advisory Council on Historic Preservation's Regulations for Compliance with Section 106 codified at 36 CFR Part 800.

Thank you for your cooperation and consideration. If you have questions concerning the above comment, contact Renee Gledhill-Earley, environmental review coordinator, at 919-807-6579 or environmental.review@ncdcr.gov. In all future communication concerning this project, please cite the above referenced tracking number.

Sincerely,

Renee Gledhill-Earley

for Ramona M. Bartos

NEW SOUTH ASSOCIATES

PROVIDING PERSPECTIVES ON THE PAST A WOMEN-OWNED SMALL BUSINESS

April 29, 2015

John Mintz
Assistant State Archaeologist
Office of State Archaeology
North Carolina Department of Cultural Resources
4619 Mail Service Center
Raleigh, North Carolina 27699-4619

RE: Nutter & Associates, Inc., Archaeological Survey, Robeson County, North Carolina

Dear Mr. Mintz,

This letter represents a management summary for an archaeological survey of 430 acres in Robeson County for a proposed poultry plant and treatment fields. This work was conducted for Nutter & Associates, Inc. of Athens, Georgia. The project includes an 85-acre poultry processing plant and several irrigation sites totaling an additional 345 acres. The survey included 15 separate Survey Areas (SA) (Figure 1).

Field methods for the archaeological survey were designed in coordination with your office. They included pedestrian walkover for the entire 430 acres, systematic shovel test survey in the 85-acre processing plant, judgmental shovel testing on the 345 acres of irrigation areas, and site recording. For the processing plant, a 50 percent sample of the 85 acres was shovel tested at 30-meter intervals. Judgmental shovel testing in the remaining survey areas focused on high probability landforms and areas with surface artifacts or features.

Fieldwork was conducted from April 20-24, 2015. New South investigated 217 shovel tests locations for this project. Of these, five contained cultural material and one was not excavated. As a result of this survey, five sites (Field Site [FS] 1–5) and seven isolated finds were identified (Figures 2–4). Fieldwork results are summarized in Table 1 and all sites and isolated finds are briefly described below.

Table 1. Summary of Survey Areas and Results

Survey Area	Type	Acreage	Shovel Tests	Sites	Isolated Finds
SA 1	Processing Plant	85	213	---	---
SA 2	Irrigation Site	15	---	---	---
SA 3	Irrigation Site	27	2	31RB524	---
SA 4	Irrigation Site	59	---	---	IF 1, IF 2, IF 3
SA 5	Irrigation Site	17	---	---	---
SA 6	Irrigation Site	10	---	FS 1, FS 2, FS 3	---
SA 7	Irrigation Site	2	---	---	---
SA 8	Irrigation Site	21	---	---	---
SA 9	Irrigation Site	3	---	---	IF 5
SA 10	Irrigation Site	1	---	---	---
SA 11	Irrigation Site	63	---	---	IF 4
SA 12	Irrigation Site	85	---	---	---
SA 13	Irrigation Site	23	---	---	---
SA 14	Irrigation Site	6	1	FS 5	---
SA 15	Irrigation Site	13	1	FS 4	IF 6
Total		430	217	6	6

Isolated Finds

New South documented six isolated finds (IF) within the survey areas. By definition, IFs retain no integrity and have no potential to provide important information beyond that which has already been documented. All IFs are recommended as not eligible to the National Register of Historic Places (NRHP) under any of the four criteria. No further work is recommended for these IFs. All six IFs are briefly described below.

IF 1 is a chunk of mortar with adhering brick fragments. It is located in the southeastern end of SA 4, approximately 100 meters east of IF 2 and 350 meters southeast of IF 3 in a cultivated rapeseed field (Figure 3). No other artifacts were observed in the vicinity. This material appears to be modern and may be related to IFs 2 and 3.

IF 2 is a wooden structure located along the southern survey boundary in SA 4 (Figure 3). The structure is just outside a cultivated rapeseed field, approximately 100 meters west of IF 1 and 250 meters southeast of IF3. IF 2, which appears to be an intact barn, is constructed of wood plank siding, wood beams, wire nails, and tin roofing panels. The structure seems to be sitting on a cinder block foundation in some areas. A rusted electrical box is attached to the outside western wall. Modern beer bottles were observed around the outside of the structure. This structure is likely modern and may be related to IFs 1 and 3.

IF 3 is a partially collapsed residence in the center of SA 4, approximately 250 meters northwest of IF 2 and 350 meters northwest of IF1 (Figure 3). The structure is surrounded on all sides by a cultivated rapeseed field. The residence sits on a brick and cinder block foundation and is constructed of wood beams, wood plank siding, wire nails, tin panels, and asphalt roofing tiles. There is a pile of burned bricks in the center of one of the rooms, away from the chimney, which may indicate a house fire. Artifacts around the perimeter of the structure include whiteware, container glass, plastic-encased electrical wire, and unidentified brick fragments. Approximately 50 meters south of the collapsed residence is a small wire cage/animal enclosure and a brick rubble heap with a pickup truck cap. This area may have served as a garage for the residence. This structure is likely modern and may be related to IFs 1 and 2.

IF 4 is a partially collapsed structure located at the northern end of SA 11 (Figure 2). IF 4 is not likely a residence, as it has a tall windowless barn-like form similar to IF 2 in SA 4. The structure sits on a cinderblock foundation and is constructed of wood beams, wire nails, tin roofing panels, and strips of faux brick paneling nailed to the siding. No artifacts were observed around the perimeter of the structure that would indicate a domestic function.

IF 5 is a small collapsed rectangular structure, located just inside the tree line along the eastern boundary of SA 9 (Figure 4). The structure measures approximately six meters wide by eight meters long and is constructed of wood beams, wire nails, tin roofing panels, and Thermax insulation. Thermax is manufactured by Dow, which has only existed for the last two decades and indicates that IF 5 is a modern structure. No artifacts were observed or collected around the perimeter.

IF 6 is a historic surface find in SA 15, approximately 60 meters southeast of FS 4 (Figure 2). It consists of one plain ironstone fragment and is likely associated with the historic scatter in FS 4. It was recorded as an isolated find due to its distance from FS 4.

<u>Archaeological Sites</u>

New South documented five newly identified archaeological sites (FS 1–FS 5) and one previously recorded site (31RB524) within the survey areas. All are briefly discussed below.

FS 1 is a historic artifact scatter on a slight rise in a cultivated field within SA 1 (Figure 3). The soil stratigraphy at FS 1 contains a 20-centimeter-thick brown loamy sand plow zone overlying a yellowish brown sandy clay subsoil with mineral staining. Artifacts were recovered from four positive shovel tests and a surface collection (15-meter radius) (Figure 5). The artifact assemblage includes historic ceramics (whiteware, stoneware) and container glass (green, clear, brown, cobalt, aqua). Two brick fragments were also recovered. This site contains a secondary deposit and retains no integrity. It has no potential to provide important information regarding the historic use of the area. New South recommends that FS 1 is not eligible to the NRHP. No further work is recommended for this site.

FS 2 is a historic artifact scatter SA 1, approximately 95 meters southeast of FS1 (Figure 3). It contains a small surface scatter of historic material between Shovel Tests 6 and 7 on Transect 6 (Figure 5). Both adjacent shovel tests were negative. No subsurface testing was conducted within the site. Stratigraphy at this site is similar to FS 1's plow zone and subsoil. Artifacts were recovered from a four-meter-radius surface collection. The assemblage includes machine made brick fragments, concrete fragments, and one fragment of a milk glass canning seal. This site contains a secondary deposit and retains no integrity. It has no potential to provide important information regarding the historic use of the area. New South recommends that FS 2 is not eligible to the NRHP. No further work is recommended for this site.

FS 3 is another historic artifact scatter in SA 1, approximately 130 meters southeast of FS 2 and 225 meters southeast of FS 1 (Figure 3). The stratigraphy in FS3 consists of a 25-centimeter-thick brown loamy sand plow zone overlying a yellowish brown clay subsoil. Artifacts were recovered from one positive shovel test and a 15-meter-radius surface collection (Figure 6). The artifact assemblage includes whiteware and clear container glass from the surface, and one unidentified metal fragment from the plow zone. This site contains a secondary deposit and retains no integrity. It has no potential to provide important information regarding the historic use of the area. New South recommends that FS 3 is not eligible to the NRHP. No further work is recommended for this site.

FS 4 is a historic artifact scatter in the center of SA 15, approximately 260 meters southwest of FS 5 and 60 meters west of IF 6 (Figure 2). The site is in a cultivated field. Artifacts were recovered from a 30-meter-radius surface collection (Figure 7). One shovel test was placed in the center of the densest surface scatter, but it was negative for cultural materials. The artifact assemblage collected from the surface includes whiteware and container glass (clear, aqua, amethyst). Stratigraphy at FS 4 consists of a 20-centimeter-thick grayish brown loamy sand plow zone overlying a very dark grayish brown clay subsoil. This site contains a secondary deposit and retains no integrity. It has no potential to provide important information regarding the historic use of the area. New South recommends that FS 4 is not eligible to the NRHP. No further work is recommended for this site.

FS 5 is a historic artifact scatter in SA 14 (Figure 2). The site is in a plowed agricultural field and likely corresponds to the foundation of a demolished residence located approximately 90 meters northeast of the site, outside the SA 14 boundary. There is a small modern trash dump approximately 25 meters northeast of the site immediately outside the survey area. Artifacts were recovered from one positive shovel test and a 10-meter-radius surface collection (Figure 8).

Artifacts recovered from the shovel test include brick fragments, wire nails, and container glass (clear and brown). Stratigraphy at the site includes a 15-centimeter-thick grayish brown loamy sand plow zone, a 25-centimeter-thick mottled strong brown and black clay, and a very dark gray brown sand. Based on the stratigraphy, this site is disturbed down to at least 40 centimeters. Brick fragments are present in the shovel test at 25 centimeters below ground surface. This site contains a secondary deposit and retains no integrity. It has no potential to provide important information regarding the historic use of the area. New South recommends that FS 5 is not eligible to the NRHP. No further work is recommended for this site.

Site 31RB524 is a previously recorded site that partially overlaps the southern tip of SA 3 (Figure 3). It was recorded a few months ago for a pipeline survey and no information on the site has been submitted to the Office of State Archaeology (OSA). At the time of survey, New South Associates had no information on this site other than its state number and boundary. It is located in a wooded area with recent pine growth, mixed hardwoods, and little to no understory. No artifacts or historic properties were observed during the initial pedestrian survey of SA 3, but orange flagging tape was noted in an area that seemed to correspond to the northern boundary of 31RB524. Two shovel tests were excavated to investigate the portion of the site within SA 3. Stratigraphy in these tests included 40 centimeters of grayish brown fine sandy loam plow zone overlying brownish yellow sand. No artifacts were collected from the shovel tests. A pile of tin roofing panels, similar to those used on the structures in SA4 and SA11, was observed approximately 10 meters west of one of the shovel tests, indicating that the previously recorded site may be historic. The site boundary may reflect historic property line or the extent of a surface scatter that may have been collected. Based on the current survey, the portion of the site within SA 3 contains no intact deposits or cultural material and would not contribute to its NRHP eligibility. New South recommends that no further work for this site.

Summary and Recommendations

New South investigated 15 survey areas totaling 430 acres for a proposed poultry plant irrigation sites. The survey identified six isolated finds (IF 1-IF 6), five new archaeological sites (FS 1-FS 5), and one previously known site (31RB524). All were historic or modern and contained secondary cultural deposits or surface features. None of the identified resources retained integrity. None exhibited the potential to provide important information on the historic use of the area. New South recommends that all six isolated finds and all six sites as not eligible to the NRHP under any of the four criteria. No further archaeological work is recommended for this project.

A full draft technical report for this project will be submitted by June 5, 2015. If you have any questions or comments, please do not hesitate to call me at (336) 379-0433 or email me at dgregory@newsouthassoc.com.

Sincerely,

Danny Gregory, RPA
New South Associates, Inc.
408B Blandwood Avenue
Greensboro, North Carolina 27401

Cc: Erin Harris, Nutter & Associates, Inc.

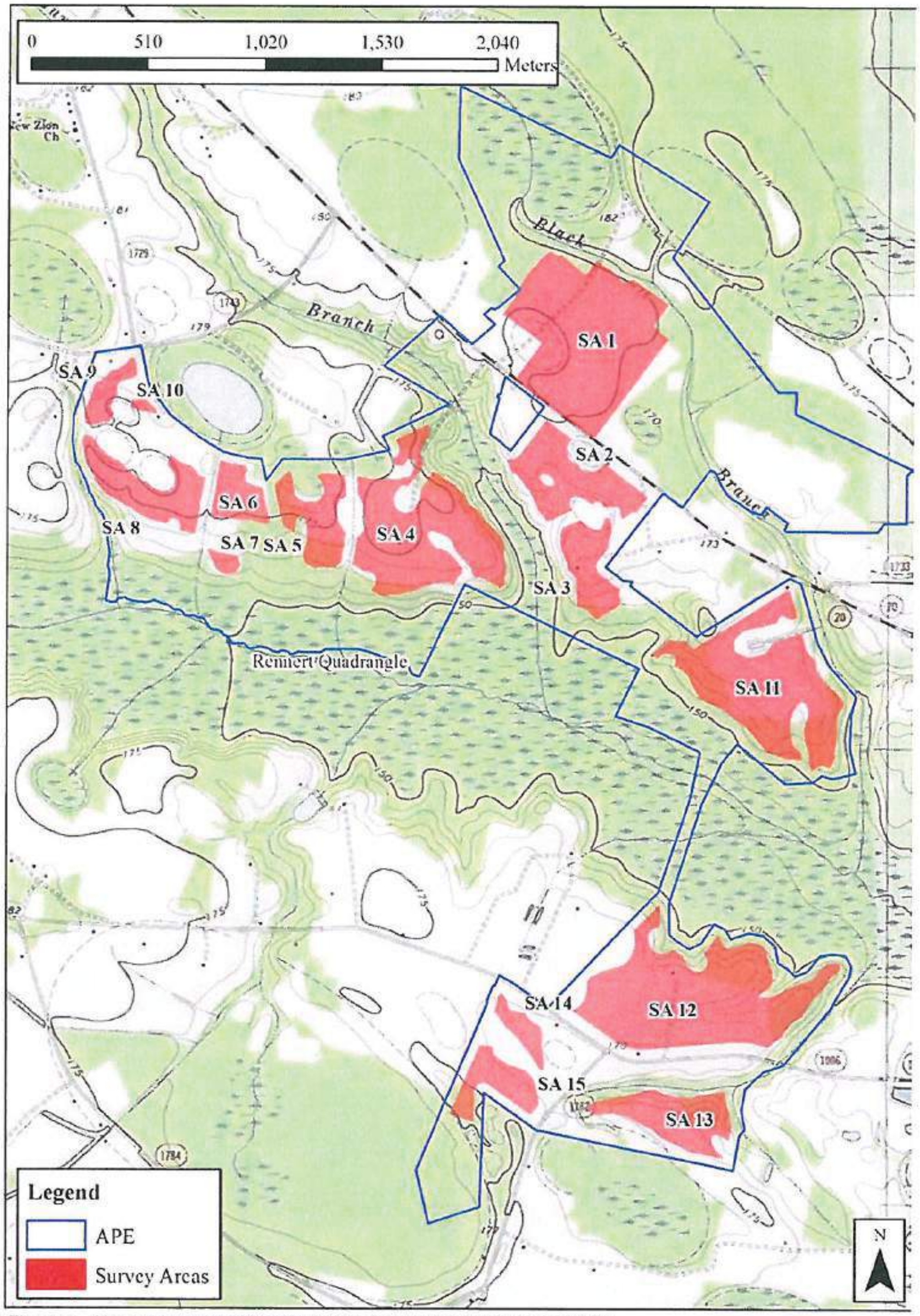


Figure 1. Map of Area of Potential Effects Showing Survey Areas (SA)

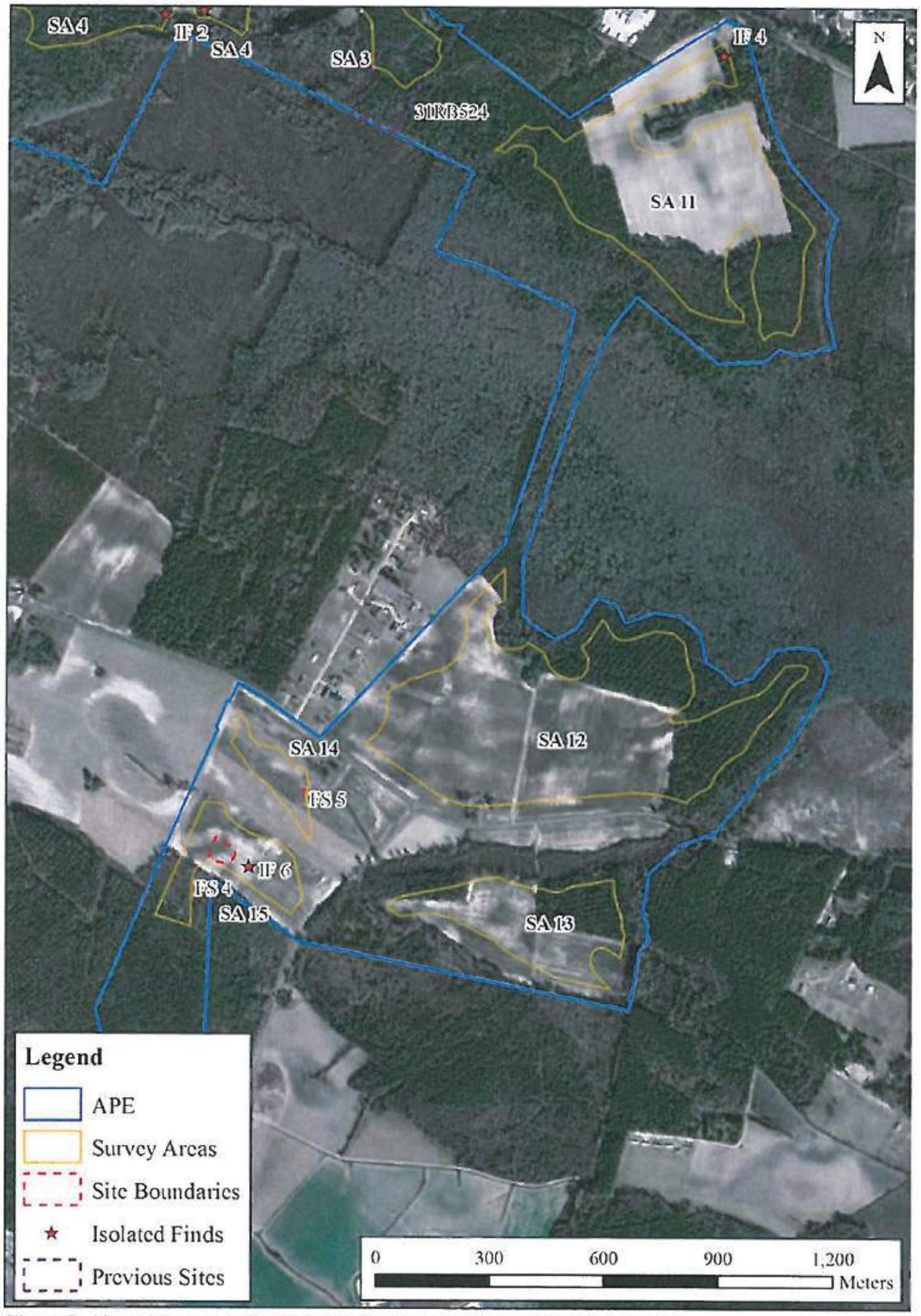


Figure 2. Map of Survey Areas Showing Cultural Resources (Southern Portion)

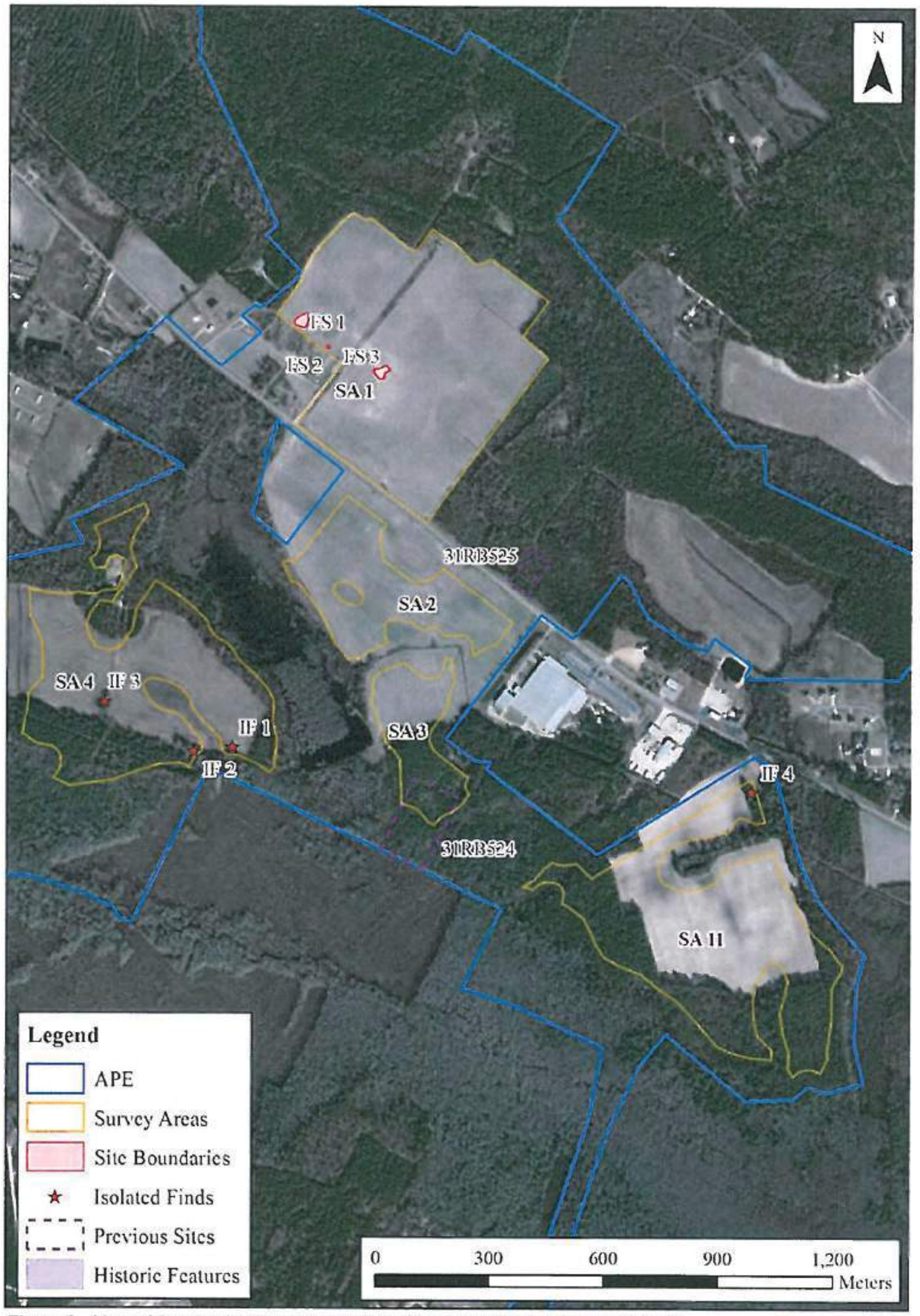


Figure 3. Map of Survey Areas Showing Cultural Resources (Northern Portion)

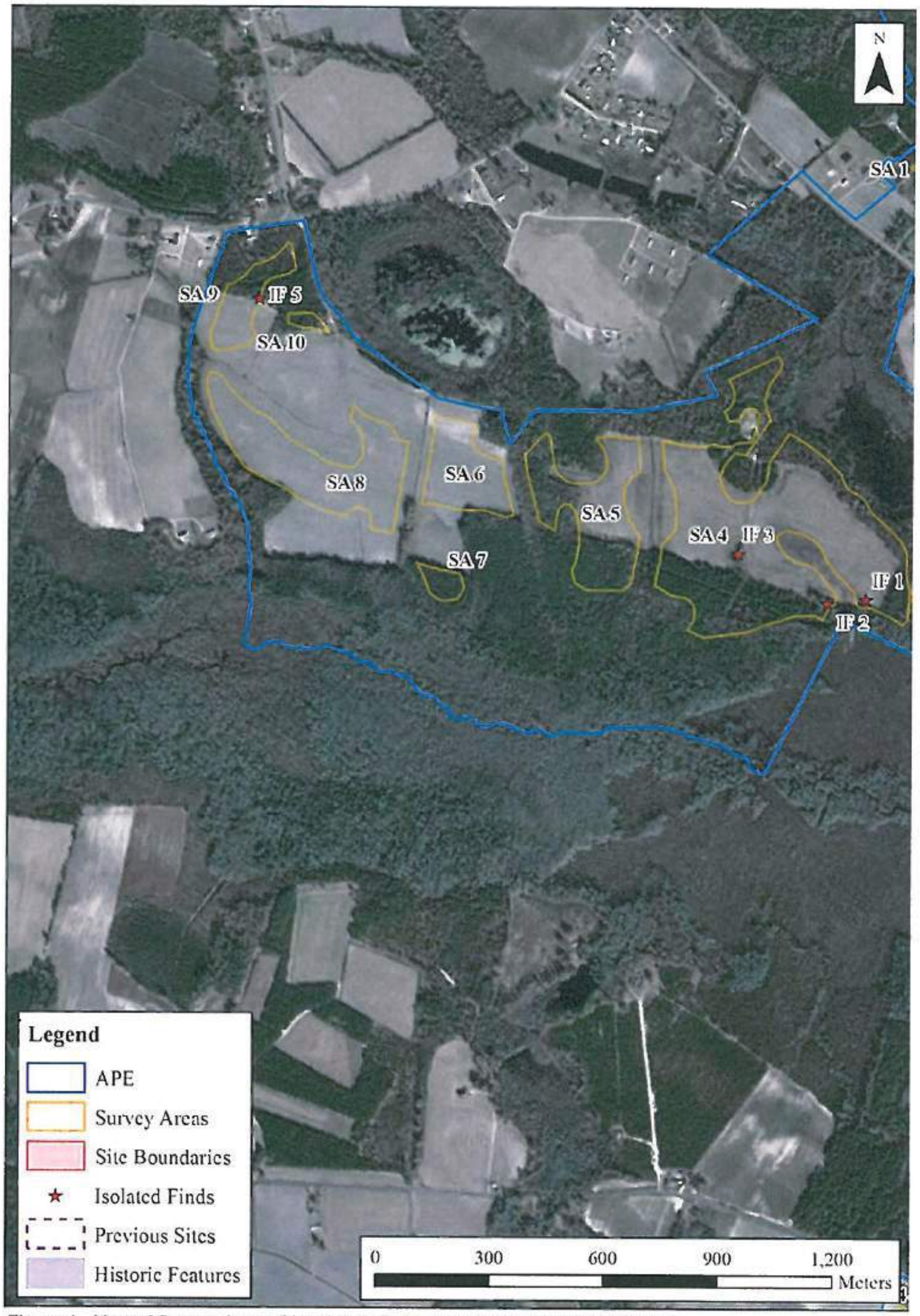


Figure 4. Map of Survey Areas Showing Cultural Resources (Western Portion)

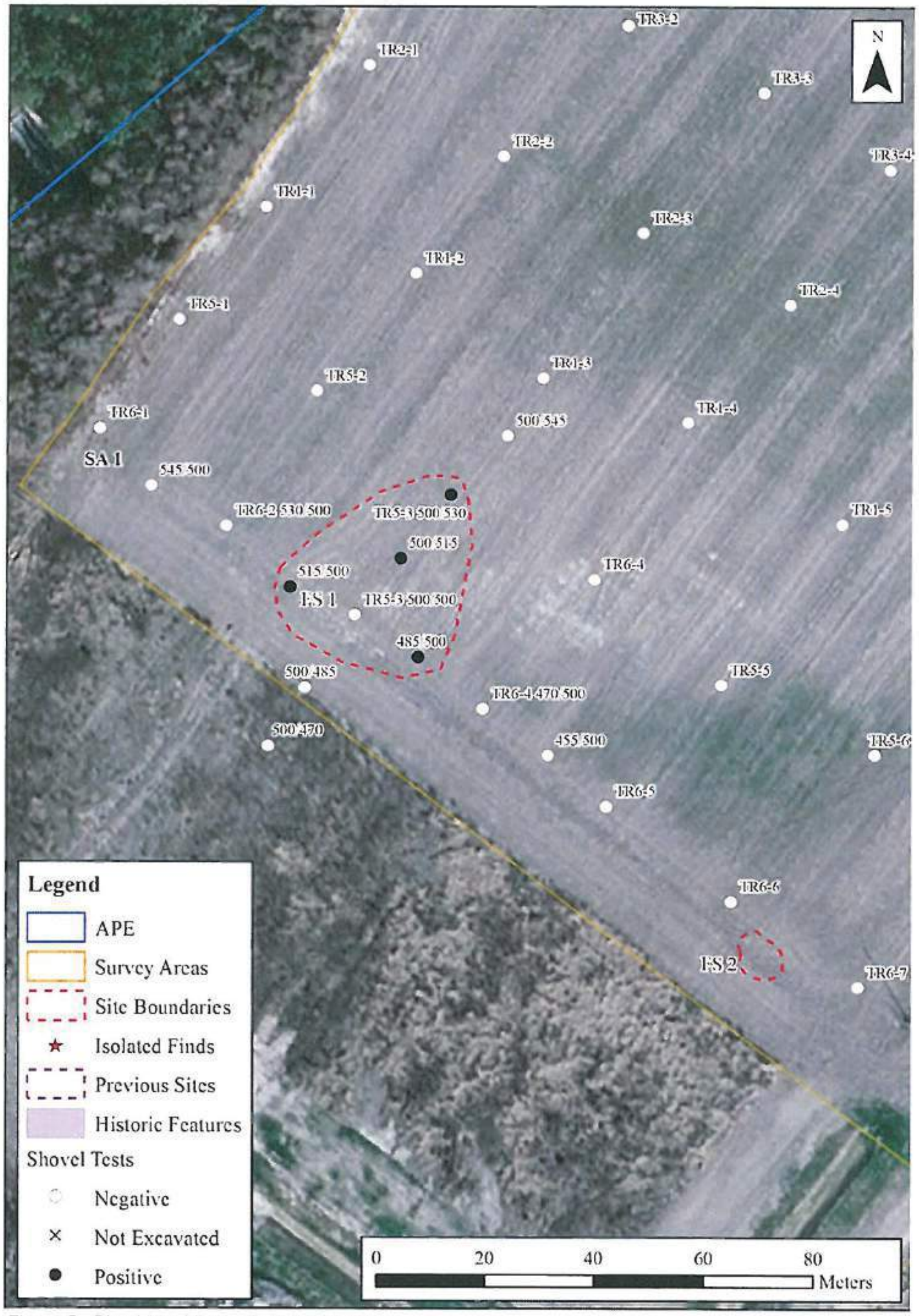


Figure 5. Plan View Maps of FS 1 and FS 2

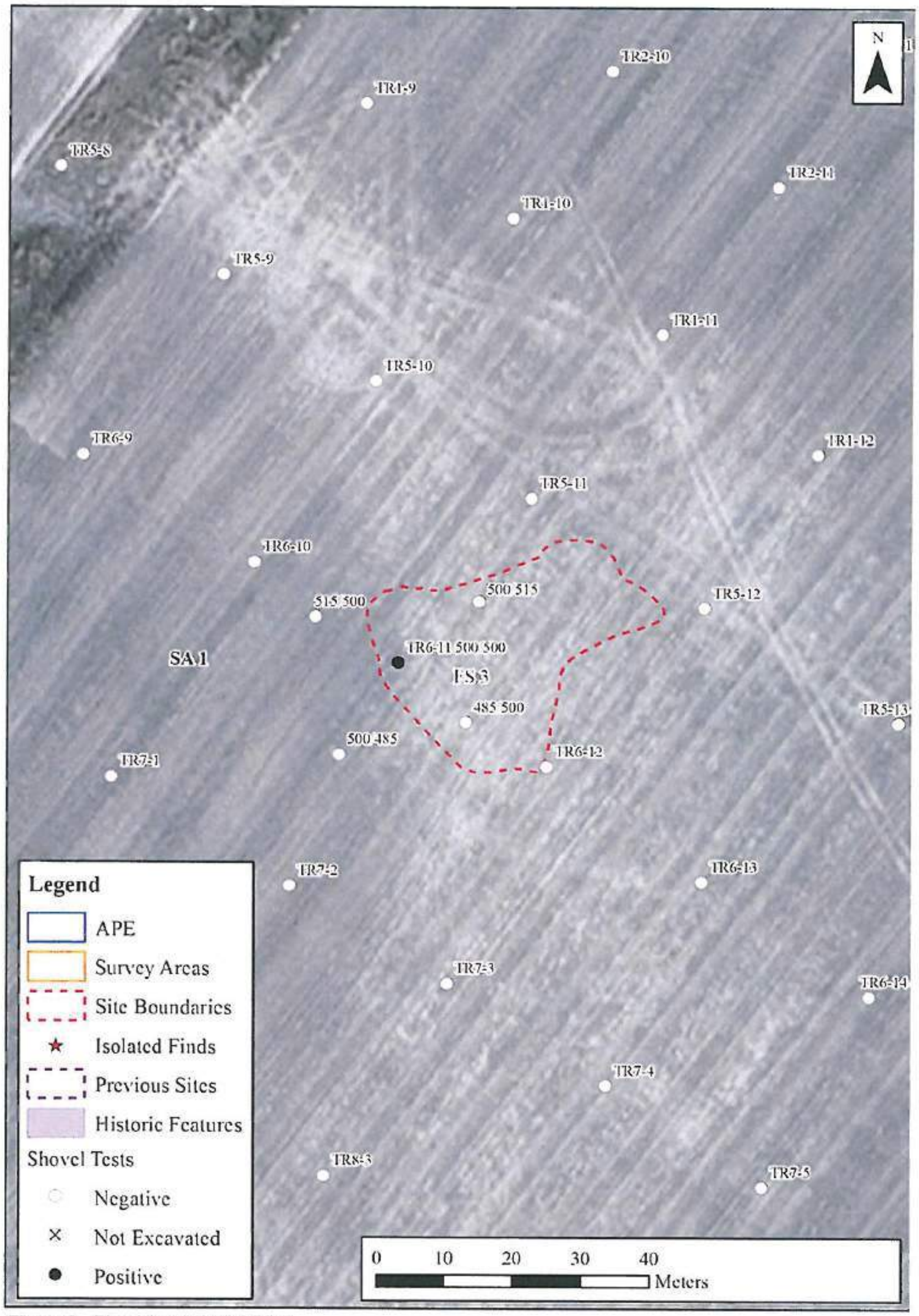


Figure 6. Plan View Map of FS 3

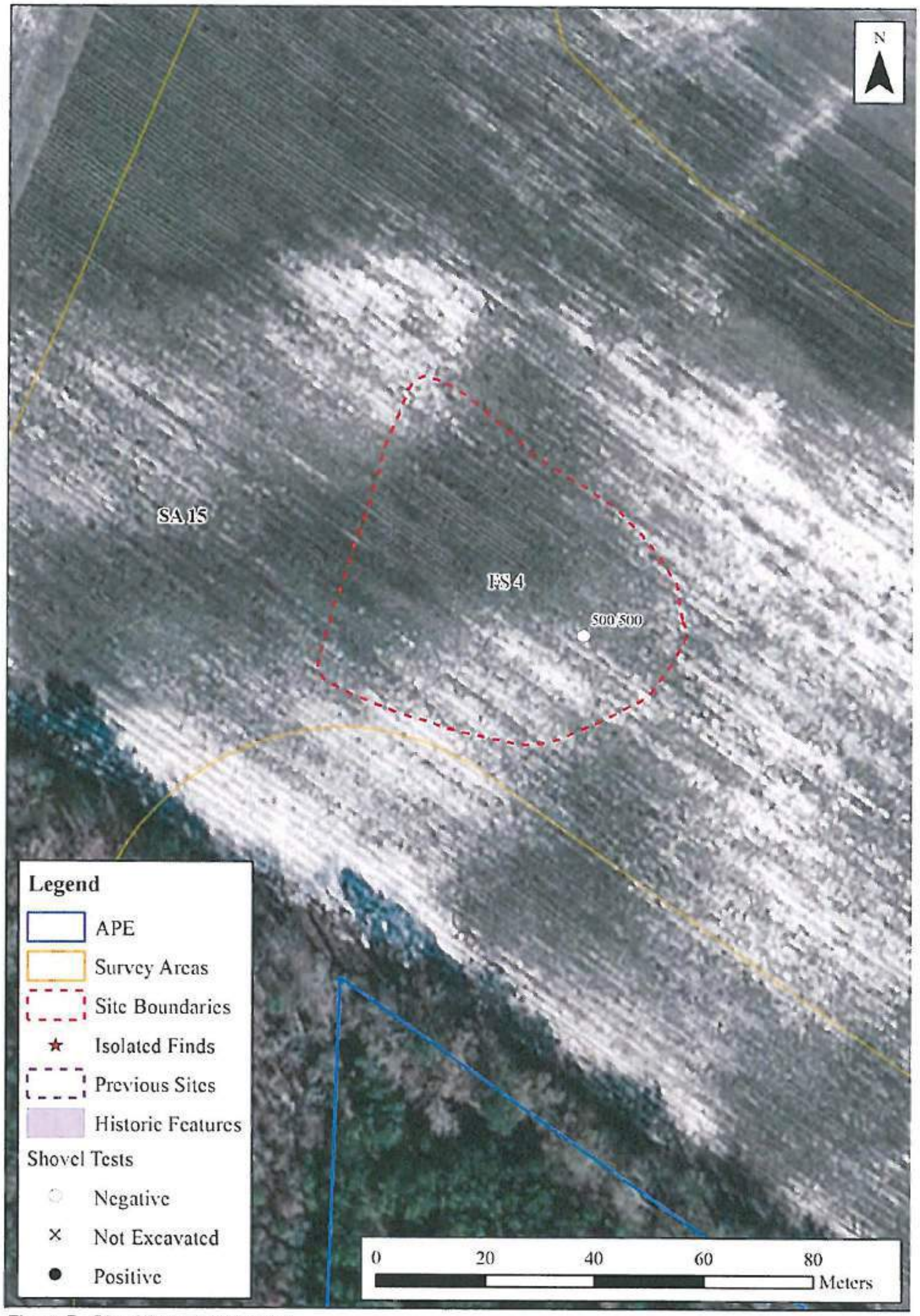


Figure 7. Plan View Map of FS 4

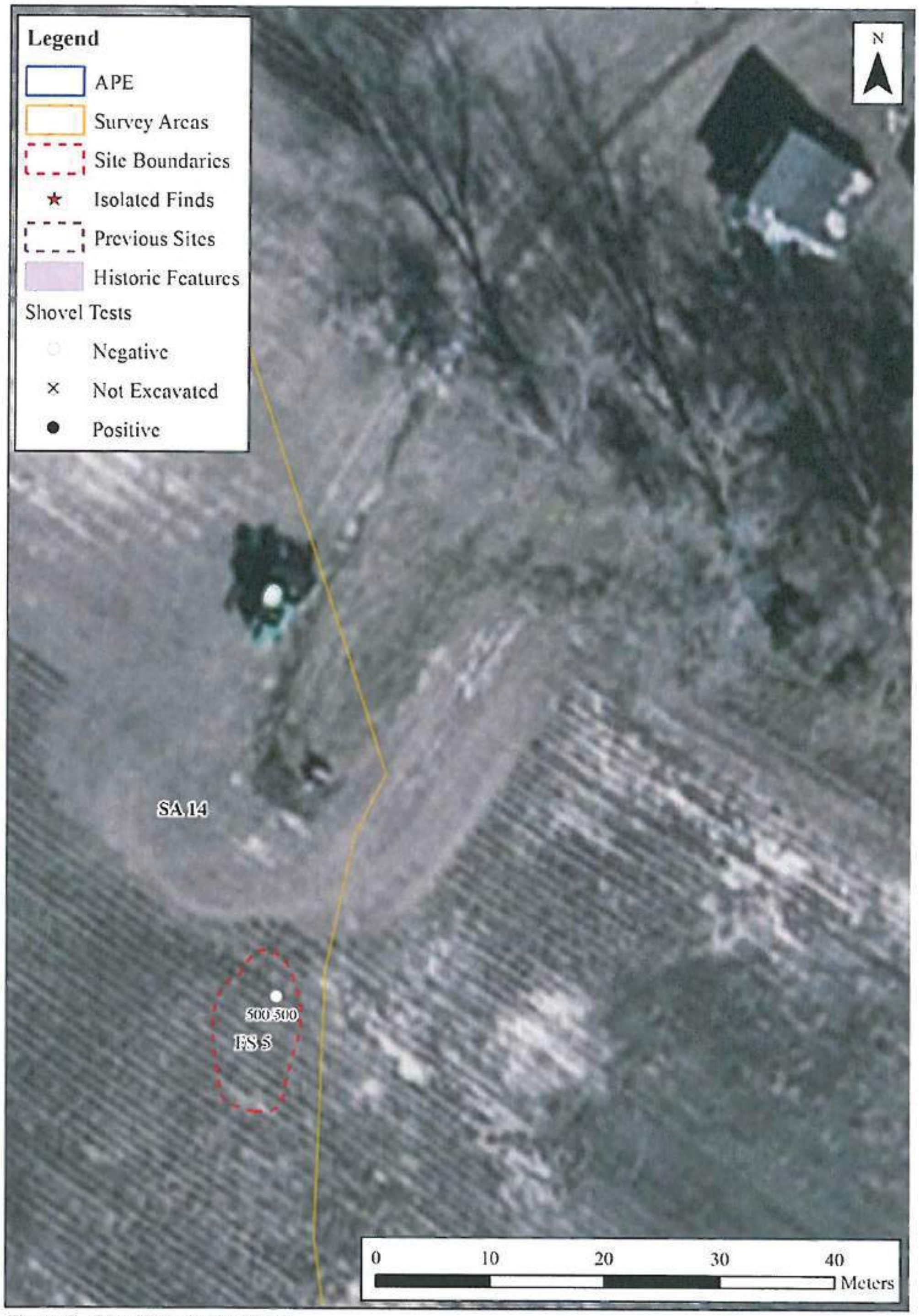


Figure 8. Plan View Map of FS 5

APPENDIX K

NOTICE OF VIOLATION DOCUMENTS

North Carolina Department of Environmental Quality

Pat McCrory
Governor

Donald R. van der Vaart
Secretary

September 25, 2015

CERTIFIED MAIL
RETURN RECEIPT REQUESTED
7012 3050 0001 9398 4811

Bob Billingsley – Director of Development
Sanderson Farms, Inc. (Processing Division)
Post Office Box 988
Laurel, Mississippi 39941-4109

Subject: **Notice of Violation/With Intent to Enforce**
NOV-2015-CV-0007
Sanderson Farms – St. Pauls Facility
Permit No. WQ0037772 (DRAFT emailed 26 August 2015 to Sanderson Farms)
Robeson County

Dear Mr. Billingsley:

You are hereby notified that the Fayetteville Regional Office of the Division of Water Resources is considering taking enforcement action for a violation of North Carolina General Statute 143-215.6A (2), failing to secure a permit required by North Carolina General Statute 143-215.1(a) (2) and codified under 15A NCAC 02T .0104 ACTIVITIES WHICH REQUIRE A PERMIT before starting construction.at the Sanderson Farms Incorporated – St. Pauls facility. Sanderson Farms has been emailed a DRAFT permit on 26 August 2015 for a wastewater treatment and irrigation system for the subject facility. Documentation of the violation of General Statutes and WASTE NOT DISCHARGED TO SURFACE WATERS rule are provided below by the Division of Water Resources:

Violation 1: Starting Construction without a valid permit:

A public hearing was held for the DRAFT permit (WQ0037772) on the evening of 17 September 2015 in the Town of St. Pauls, Robeson County, North Carolina. Several commentors stated that construction had started at the Sanderson Farms – St. Pauls facility prior to the issuance of a final permit to Sanderson Farms Incorporated. On 18 September 2015, Division of Water Resources (DWR) personnel visited the site and documented (photographs) excavation activities taking place in the vicinty of the proposed wastewater treatment infrastructure (holding lagoon, waste sludge lagoon and anaerobic lagoon) consistent with the site plan application prepared by Chas. N. Clark Associates (CNC). An equipment operator, with Allen Grading Company, was questioned about the area of excavation that was being undertaken. The operator produced a set of site plans from a Allen Grading company vehicle and indicated that the soil being excavated was from the holding lagoon. Upon further discussion, the operator stated that the floor of the holding lagoon was at "rough grade".

225 Green Street – Suite 714 – Fayetteville, North Carolina 28301-5095
Phone: 910-433-3300\Fax: 910-486-0707\Customer Service: 1-877-623-6748

Required Corrective Action for Violation 1:

Upon receipt of this Notice of Violation (either by US Mail or email) cease any and all construction/grading activities related to the proposed wastewater infrastructure (holding lagoon, anaerobic lagoon, waste sludge lagoon, clarifier, aeration basin, anoxic basin, etc.) at the Sanderson Farms – St. Pauls facility.

If additional fill soils are needed to continue grading activities on the production facility foundation; seek other sources of borrow from on-site locations (i.e. proposed stormwater basins, dedicated borrow areas or off-site sources near the Sanderson Farms – St. Pauls facility).

Please be advised that construction of the proposed wastewater treatment facilities without a valid permit is a violation of North Carolina General Statute 143-215.1 and may subject Sanderson Farms Incorporated to appropriate enforcement action(s) in accordance with North Carolina General Statute 143-215.6A. Civil penalties of up to $25,000 per day per violation may be assessed for failure to secure a valid permit required by North Carolina General Statute 143-215.1 prior to starting construction of any wastewater treatment facilities.

If you have an explanation for the violation or documentation that you wish to present to the Division of Water Resources; please respond in writing to the Fayetteville Regional office within **ten (10)** days after receipt of this Notice. Your information will be reviewed and considered when making a determination of whether to proceed with an enforcement action and administrative penalty.

Please note that this Notice does not prevent the Division of Water Resources from taking additional enforcement action(s) for this violation if not corrected or for any future violations

If you have any questions concerning this matter, please do not hesitate to contact me at (910) 433-3326 or Jim Barber at (910) 433-3340.

Sincerely,
Belinda S. Henson

Belinda S. Henson
Regional Supervisor
Division of Water Resources
Water Quality Regional Operations Section

cc: Non-Discharge Central Office File
Non- FRO File
Nathaniel Thornburg, NDPU Supervisor (electronic copy)

Brenda

Sanderson Farms, Inc.
GENERAL OFFICES
Post Office Box 988 • Laurel, Mississippi 39441-0988
Telephone (601) 649-4030 • Facsimile (601) 426-1461

BOB "PIC" BILLINGSLEY
Director
Development & Engineering

10-1-15
sent UPS overnight
to Ms Henson
& Mr. Risgaard

September 30, 2015

Ms. Belinda Henson, Regional Supervisor
N.C. Department of Environmental Quality - Water Resources
225 Green Street, Suite 714
Fayetteville, North Carolina 28301

RE: Sanderson Farms Processing Plant – St. Pauls, North Carolina

Dear Ms. Henson:

The purpose of this correspondence is to address your request for comments concerning grading at the above referenced site.

I have prepared a map of the Overall Site Layout that delineates Borrow Area 1 and Borrow Area 2. This map was forwarded electronically to Mr. Jon Risgaard on September 29, 2015.

Consider the following points when referring to the map:

1. The limits of the proposed "building pad" also include parking lots, outbuildings, access drive, etc., all of which require engineered fill.

2. When considering areas available for borrow excavation of soil to construct the building pad, the logical choices were the two open fields on either side of the building pad. Sanderson Farms did not want to clear wooded areas to obtain borrow material.

3. Soil borings made in Borrow Area 1 indicated that a portion of the soil was suitable for engineered fill. The pertinent soil borings are shown on the aforementioned map. Only suitable soil has been excavated from Borrow Area 1.

4. Borrow Area 1 is unable to furnish all of the required borrow. As such, Borrow Area 2 was tested to demonstrate that the soil here is also suitable for engineered fill.

5. Sanderson Farms has not contracted nor committed to the construction of the Wastewater Treatment Facility which includes aeration basin, anoxic basins, clarifier, disinfection and land treatment system. Please be assured that Sanderson Farms will not proceed with any construction of the waste treatment facility including the aerobic lagoon, holding pond, waste sludge lagoon, and stormwater pond. To that end, Sanderson Farms has ceased all excavation in Borrow Area 1 and will not resume operations in Borrow Area 1 until receipt of the permit to construct the Wastewater Treatment facility.

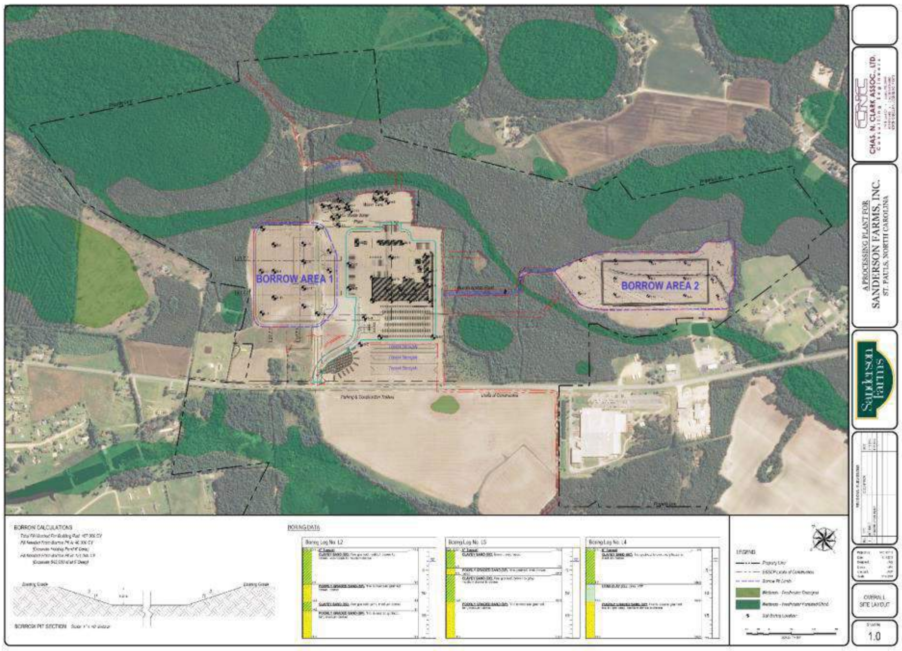
We trust that this letter has addressed your questions and concerns in a satisfactory manner. If there is additional information or explanation required by Sanderson Farms, we will be happy to furnish it.

Sincerely,

Sanderson Farms, Inc.

Bob Billingsley
Director of Development and Engineering

cc: Jon Risgaard, NCDEQ


BORROW AREA 1
BORROW AREA 2
BORROW CALCULATIONS
BORING DATA
LEGEND
CHAS. N. CLARK ASSOC., LTD.
Consulting Engineers
A PROCESSING PLANT FOR
SANDERSON FARMS, INC.
ST. PAULS, NORTH CAROLINA
Sanderson Farms
OVERALL SITE LAYOUT
1.0